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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

STUDY OF FIRING FAILURE IN MASSIVE TALC



BY

HOWARD F. CARL

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REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

STUDY OF FIRING FAILURE IN MASSIVE TALC^{1/}

By Howard F. Carl^{2/}

INTRODUCTION

Talc is a hydrous magnesium silicate mineral found throughout the world in deposits of economic importance. This mineral occurs in different physical forms and varying degrees of purity, both of which affect its ultimate commercial usage. Talc is used in finely ground condition by the ceramic, paint, paper, rubber, cosmetic, and other industries. Most domestic talc production is of this type. Talc also occurs, although much less frequently, in massive, fine-grained, fairly homogeneous bodies; the impure varieties are the familiar soapstones, and the purer form is frequently called "steatite." Because of certain properties, the purest grades of this massive variety have a monetary value about 20 times that of the ground talc.

One desirable property of this massive talc is its amenability to accurate cutting, machining, and working in many ways, similar to a hard wood or soft metal, and then firing without warping or appreciable shrinkage into a hard, refractory ceramic body. Consequently, shapes that cannot be formed conveniently by molding and pressing can be produced readily with ordinary machine tools. When talc is fired to about 1,100° C., it is converted to a ceramic body with certain very desirable physical properties. This fired material has a hardness and toughness frequently superior to steel. It is a refractory and an exceptionally good electrical insulator. When formed from a high-grade talc essentially free from iron, it has unusually low dielectric losses, even at very high frequencies.

These properties give this pure grade of massive talc a high market value and make it an "essential" raw material. Samples that fire satisfactorily and are of sufficient purity are made into special shapes, fired, and used in high-frequency radio tubes and less extensively in other radio equipment where the particular physical and electrical properties are important. Recently this use alone has consumed about one million dollars worth of finished products per year. Although substitutes are being developed and are used to some extent, no completely satisfactory one has been made for certain of the most essential uses. Fired products made from less-pure grades of massive talc - that is, those containing up to several percent

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of iron and lime, which are the usual impurities - have numerous other uses, such as for insulators and spacers in certain radio equipment, for nozzles for gas burners and sand-blast equipment where refractoriness and toughness are essential, and for spacers and other "kiln furniture" where stability under repeated firing and cooling is important.

The lower-grade material can be and at present is supplied entirely from domestic sources. However, the present domestic production of the high-grade "critical" block talc has been extremely sporadic, amounting to only a few tons per year. As a result, practically all high-grade talc of this type has to be imported. In 1943 the demand amounted to about 55 tons per month, but partly through the use of substitutes the present (fall, 1944) requirements have been reduced to about 35 tons per month. India, the chief foreign source, can supply much more than this, while Sardinia, the other important producing locality, can furnish somewhat less than India, although in the fall of 1944 it supplied none. Since almost all the high-grade material necessary for certain essential uses must be imported, this type of talc is classified in Group I on the WPB Material Substitution and Supply List. Supplies of Group I materials are insufficient for war plus essential industrial demands. With the added possibility that further developments in radio will necessitate other uses of this material for which substitutes may not be suitable, the "critical" importance of this mineral may be appreciated. The imported material, in rough lump form, sells for \$100 to \$150 per ton, depending on size and grade, and the domestic rough lump for about \$160 per ton. Sawed prisms of acceptable size from any source bring \$200 per ton. Although the total present consumption, in tons, may seem comparatively small, the value of the finished product is considerable, not only when measured in terms of dollars but also because of its strategic uses. There is, as yet, no completely satisfactory substitute.

ACKNOWLEDGMENTS

This work was performed at the Eastern Experiment Station of the Bureau of Mines, College Park, Md. (J. B. Zadra, acting regional engineer), and was initiated at the request of Paul M. Tyler.

Appreciation is expressed to M. Kirchberger & Co., Inc., Brooklyn, N. Y., who kindly furnished the imported talcs and one domestic sample for this study. Dr. Felix Chayes, associate petrographer, performed the petrographic examination of the thin sections.

OBJECT OF INVESTIGATION

In addition to losses resulting from the selection of raw material of uniform composition and structure and low in mineral impurities, there is a considerable loss due to cracks which occur (1) in the original raw material, (2) in cutting it to proper-size blanks, (3) in forming the blanks, (4) in their firing, and finally (5) after cooling of the fired product. Therefore, only a small percentage, probably less than 0.1 per cent, of the initial supply of raw material at the mine can be made into

acceptable finished parts. This adds greatly to the cost of the product and results in a rather inefficient use of the raw material. The cracking which occurs after the selection and machine work has been completed represents a serious loss, and yet very little work has been done to determine the causes or possible prevention of these cracking failures.

Since the Bureau has been investigating massive talc deposits in order to locate additional sources of high-grade material, and since the best experts in the talc industry have been unable to differentiate between good and poor material with regard to its firing characteristics by visual observation or any other test short of actual firing, this study of the firing properties of massive talc was undertaken with the following objectives:

1. To discover and study the causes of cracking failures in massive talc on firing.
2. To develop tests that might be applied to talcs to indicate their firing characteristics.
3. To select the most specific of these tests that might be applied in the field to a specimen or sample of a talc deposit.

GENERAL CONSIDERATIONS

A brief examination of samples of talc from various deposits as well as from different locations within the same deposit immediately revealed the considerable variations that occur in many of the properties of this material. The results of tests on different talcs likewise varied considerably. That is, although different specimens from the same sample of talc, if not too large, usually showed similar characteristics, almost every sample of talc reacted differently to the various tests performed on them. This variation in the characteristics of talcs has been a major impediment to the successful correlation of data obtained from tests of different talcs and by different experimenters. However, this study, made on both high- and low-grade block talcs, has resulted in certain information which should be of interest particularly to those engaged in commercial production of the fired product.

Thirty different samples of talcs were studied from sources in Maryland, Montana, California, Sardinia, South India, and the United Kingdom (North India).

EXPERIMENTAL WORK

As the samples submitted for examination varied widely in size and shape, pieces were cut roughly 1 inch square and 1/4 inch to several inches thick and usually somewhat smoothed with sandpaper. The smoother surface allowed more certain detection of surface cracks which might result from the firing tests.

About 150 different specimens were studied, their composition, texture, grain size, and structure were noted, and their behavior under various firing conditions was observed. Thin sections were made of 23 different talcs. The apparent specific gravities of 12 representative talcs were determined. A few samples having widely different grain structures were examined by X-ray diffraction. Several other minor tests were also performed, but these gave negative results.

The details of the tests and the results obtained therefrom are reported below.

FIRING STUDY

The firing tests were performed in a muffle-type electric furnace heated with Globar elements. The silicon carbide muffle had a small opening to the atmosphere in the rear. Quite close control of temperature and rate of increase in temperature was maintained by suitable automatic control equipment.

The talcs were initially tested by being heated from room temperature to a maximum of $1,100^{\circ}\text{C}$. at a uniform rate of temperature rise of 5°C . per minute. However, as the study indicated that certain critical temperature ranges existed, the heating program of the furnace was changed to allow a much slower heating rate through these critical ranges. Some specimens from each talc sample were heated rapidly by being inserted into the hot furnace maintained at various temperatures and then raised to the maximum. Many were removed for inspection at various temperatures during the heating schedule and then replaced. In this manner the temperature at which cracks might first appear was determined.

As the samples are uniformly heated, the first critical temperature range becomes evident when the furnace reaches about 600°C . Differential thermal analysis^{3/} shows that, as talc is heated, an endothermic reaction occurs which is associated with the loss in weight between 400° and 450°C .^{4/} This is interpreted to be due to removal of the loosely held water in excess of the 1 molecule present as part of the talc structure.^{2/} Some samples actually exploded around 600°C . Others were found to be badly cracked when removed for examination (fig. 1). Certain samples that would have cracked badly under the normal heating rate could be heated to the higher temperature without developing appreciable cracks if taken more slowly through the 600°C .

^{3/} Ewell, R. H., Bunting, E. N. and Geller, R. F., Thermal Decomposition of Talc: Nat. Bureau of Standards Jour. Research, vol. 15, November 1935, pp. 551-556.

^{4/} Thermal effects due to loss of water usually are recorded in differential thermal curves about 100°C . higher than the temperature at which the water is lost under static conditions. Likewise at an indicated furnace temperature of 600°C . and a 5° per minute heating rate, the average sample temperature is probably between 50° and 100°C . lower.

^{2/} Foshag, William F., and Wherry, Edgar T., Notes on the Composition of Talc: Am. Mineral., vol. 7, No. 10, 1922, pp. 167-171.



FIGURE 1.- Fired Montana talc, showing severe cracks developed at about 600° C.

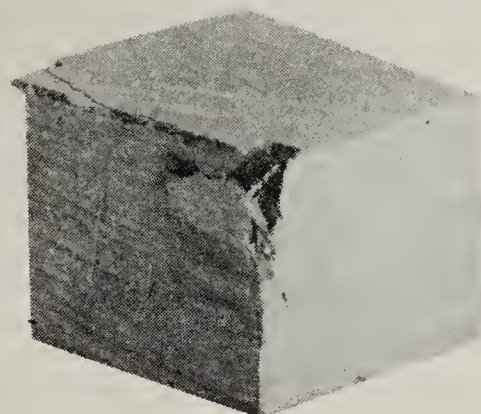


FIGURE 2.- Fired Montana talc; cracks emanate from a pocket of dark mineral impurities in the corner.



FIGURE 3.- Unfired Maryland talc, in which the light streaks are veins of oriented crystals. Their lighter color is due to the absence of iron staining.



FIGURE 4.- Fired Montana talc; part of a fractured piece showing severe cracking as a result of foliation or schistosity in the raw material.

range. Samples from various "pit areas" of the Johnny Gulch talc deposit near Ennis, Mont., illustrate these types.

In some cases different samples from the same "pit area" of Johnny Gulch would have entirely different behavior in this temperature region. Many other samples, however, are unaffected by even a quite rapid heating through this region. Those from the White Eagle mine, Inyo County, Calif., and from Marriottsville, Md., could be rapidly heated to about 900° C. without showing any sign of cracking.

This higher temperature of 900° C. is in the second critical temperature region. Up to about 800° C. the talc crystal undergoes no change in internal structure or of optical properties. Between 800° and 900° C. the remaining molecule of water is driven off, and the talc simultaneously inverts to enstatite ($\text{MgO} \cdot \text{SiO}_2$) and amorphous silica.^{6/} This expulsion of water is indicated by the endothermic peak on the differential thermal curve at about 950° C. associated with the relatively large weight loss between 800° and 850° C. Many talc samples developed more or less severe cracks when the furnace reached 900° C., depending on the size of the specimens, or somewhat above 900° C., depending on the rate at which they were heated. The Maryland talcs are of this type.

DISCUSSION OF FIRING TESTS

These tests have shown that there are several distinct and frequently interrelated causes of the development of cracks when an otherwise sound piece of talc is fired. Nonuniformity of composition is one obvious cause. If the mineral impurities that may occur in some talcs (such as chlorites, tremolite, serpentine, magnetite, titanite, carbonates, etc.) are more or less uniformly scattered throughout the talc in a finely divided state such that a heterogeneous material results, such impurities in themselves do not promote the development of firing cracks. Some Maryland talcs with finely divided mineral impurities scattered throughout will fire satisfactorily in thin pieces. Any localization or concentration of discrete particles of impurities does cause strains that may result in cracking in those regions when the talc is fired. Upon examination, numerous pieces were found to be cracked along veins or streaks of impurities or to have cracks radiating therefrom (fig. 2). The presence of a distributed iron staining, however, does not cause cracking on firing and may even aid inversion of the talc.

The actual chemical composition and physical structure of the talc body are also important factors affecting its firing characteristics. Pure mineral talc contains a variable amount of water in excess of the 1 molecule which is a part of the talc "unit cell." This excess water can be removed by heating without destroying or affecting in any way the actual crystal structure.^{7/} In addition, the desirable fine-grained and smooth-textured readily machined material contains a variable quantity of a bonding agent, probably silica in some form, and physical consolidation of the talc and this impurity

^{6/} See footnote 3.

^{7/} See footnote 3.

gives the material its convenient mechanical properties. It is supposed that this bonding agent, at least partly, affects the pore structure of the talc, and this in turn should influence the ability of water to escape from the talc body during its firing. This escape of water will be discussed further in its relation to the firing schedules.

Another characteristic that affects the firing behavior is the crystal-line orientation and grain size of the material. An orientation (foliation or schistosity) of the talc crystals may be seen frequently along fractured surfaces of the raw talc if the crystal grains are large enough and also in fired specimens that have cracked apart (figs. 3 and 4). In samples containing veins of oriented pure talc the most extensive cracks resulting from the firing process were observed to be in, parallel to, or radiating from these oriented veins. The thermal expansion attending the inversion of talc to enstatite and free silica is so low that cracks should not develop in a body in which small talc crystals are in essentially random orientation. A concentration of stresses with attendant production of cracks may result, however, if orientation is pronounced.

Most of these causes of cracking are obvious enough to be used as criteria in the selection of the raw material. In commercial practice only pieces of uniform composition and texture are usually selected, particularly in the high-grade material; but the influence of the bonding agent on cracking failures is not as well understood, although it may be related to the water content of the material.

One other very important factor in the development of firing cracks has been given scant attention - the actual firing schedule. In fact, until recently most of the firing of even the high-grade talcs was done with little or no control of the heating rate and little consideration of the maximum temperature reached. Industry appears to have little exact knowledge as to optimum firing conditions or schedules or the most suitable maximum temperature to be reached.

If there is a considerable quantity of water in the talc in excess of the "structural" water (and analyses indicate this to be quite variable, as weight losses on ignition range from about 3 to 7 percent) and if it cannot escape readily through the pore structure of the material, the body may be shattered at the lower critical temperature. Several factors may prevent or retard the escape of this water. One is certainly the degree of porosity of the material, which is determined by the quantity of bonding agent, the fineness of grain, and the degree of consolidation. Consequently, some talcs, if heated quite slowly from about 400° to 600° C., can be fired successfully to the required higher temperatures, as the water has ample opportunity to escape. If heated too rapidly they explode, particularly if the pieces are more than approximately one-quarter inch thick. Conversely, other talcs having little excess water may be inserted into the furnace at 900° C. without cracking under such rapid heating.

The actual size of the specimen being heated is an important consideration. For example, 1-inch cubes of talcs that crack badly under certain

firing conditions will fire satisfactorily as plates one-quarter inch or less thick. Consequently, many talcs that do crack when fired in large pieces may be used successfully for thin shapes. Several wedges of Maryland talcs tapering from about one-half to one-eighth inch in thickness were fired, and cracking resulted only on the thicker end. For this reason, it was considered that tests on the thicker pieces represented the most severe conditions that would be met in commercial practice.

It should therefore be evident that although talcs vary extensively in the manner in which they react to the firing process a controlled schedule of heating will give a larger percentage of crack-free fired products. As talc is not a good thermal conductor a rapid heating schedule, particularly of thick pieces, should be avoided. Although even large pieces may be raised to around 500°C . in about an hour, at this point the rate of heating should be cut to about 150°C . per hour unless it has been determined previously that such talc will withstand more rapid heating in this region. Otherwise, this 150° per minute rate should be maintained until a temperature of about 900°C . is reached. The samples should be held for approximately 1 hour at this temperature before continuing at the same rate to the maximum temperature of $1,100^{\circ}\text{C}$., as was the case in these experiments. This is particularly important when large pieces are fired.

Judging from the wide variety of talcs and various-size test pieces as here studied, it is estimated that the controlled schedule of heating resulted in a recovery of approximately 50 percent more crack-free fired specimens.

The maximum temperature to which the products should be fired depends largely on the use for which they are intended. The critically important high-frequency radio parts using high-grade talc should develop the proper "body" with the desired electrical characteristics at a particular (minimum) temperature. Other products may also have other optimum values of firing temperatures, depending on their uses. After a talc, probably monoclinic, has been inverted to orthorhombic enstatite and free (amorphous) silica, according to the reaction: $4\text{MgO} \cdot 5\text{SiO}_2 \cdot \text{H}_2\text{O} \rightarrow 4(\text{MgO} \cdot \text{SiO}_2) + \text{SiO}_2 + \text{H}_2\text{O}$, no other crystallographic change takes place until about $1,200^{\circ}\text{C}$. is reached, whereupon gradual inversion of the enstatite to monoclinic clinoenstatite takes place. This inversion is complete around $1,300^{\circ}\text{C}$., the temperature at which the silica starts to form cristobalite. Likewise, from 800° to 900°C . on up the material undergoes a gradual change in porosity and density. Consequently, the properties of the product probably vary throughout this entire temperature range from the initial inversion point to the softening or decomposition point of over $1,500^{\circ}\text{C}$. for the pure material. As this study did not include determination of the electrical properties of the fired material, this consideration of the optimum firing temperature was not investigated.

All observed cracks that have developed on fired samples of talc have been formed during the heating part of the cycle and not upon cooling. No piece was seen to crack or develop further cracks once it had been removed from the furnace, even if this was done, as was frequently the case, while

the sample was still at the maximum temperature. This is another indication that thermal expansion or contraction is not responsible for such cracking.

OTHER TESTS

Thin sections were made of 23 different talcs that were selected on a basis of variability of texture and grain size and firing characteristics. A petrographic examination was made of these sections. Differences in grain structure, such as preferred orientation, schistosity, and foliation, which would also be apparent by visual inspection of a fractured surface of the same sample, were observed. However, no diagnostic features, such as the presence of or differences in amount of any bonding agent, an aggregation of microscopic impurities, or variability in optical properties, that could be related to firing behavior or lack thereof were observed in this study.

The apparent specific gravities of about a dozen representative samples of unfired talcs were determined. Values ranged from 2.6 to 3.0. No correlation of these values with firing behavior could be made.

Although no actual quantitative measurements of hardness were made, the samples ranged from those soft enough to allow a fingernail to be embedded readily in them to those hard enough to permit only a light scratch with the fingernail. Some both hard and soft material fired poorly and some satisfactorily.

The porosities of the samples were not determined, although they obviously varied considerably. Other studies of porosity as related to firing characteristics have produced only negative results.

Certain minute surface crazing which occurs occasionally on finished commercial products after they have cooled for a period of many days was not observed in any specimens fired in these tests and hence was not investigated.

An attempt was made to evaluate the degree of crystal orientation of various samples by X-ray diffraction methods. Diffraction patterns were obtained of various samples of different crystal size and degree of orientation. Preferred orientation, where it existed, was indicated by the diffraction patterns, but such indications were no better than could be obtained by visual inspection of a fractured surface. The difference between a completely random distribution of crystals and slight preferred orientation can be detected by this method or other diffraction techniques, but such small differences are unimportant in this study. Likewise such a method of evaluation would seldom be available to those interested in grading massive talcs.

A popular belief as to the actual origin of these firing cracks was investigated but could not be substantiated. It has been assumed rather generally that many, or even a majority, of cracks result from the further development of minute undetected "hairline" cracks initially present in the raw talc or that original surfaces of weakness open up when the material is fired. No evidence was found of any such initial cracks in apparently solid talc which did crack when fired. Conversely, some samples with small but

plainly visible cracks were fired completely with no further development of the initial cracks. Attempts to observe these "hairline" cracks by radiography were as unsuccessful as have been attempts by others to reveal them by fluorescent liquid penetration. They apparently do not exist.

SUMMARY OF CONCLUSIONS

The firing studies of massive talcs have indicated the importance of a controlled firing schedule. Two critical temperature ranges have been determined, one at approximately 600° C. and the other around 900° C. The desirability of a slow rate of temperature rise through these regions was shown by the results of the controlled firing tests. The dependence of successful firing of talcs on their uniformity of composition, structure and texture, fineness of grain, and freedom from preferred orientation and their ability to lose their water of composition readily have been demonstrated. The assumption that initial minute cracks or incipient planes of weakness are a major cause of firing failure could not be substantiated.

It has become evident as a result of this study that certain specifications with respect to physical and chemical properties of massive talc must be met to make a satisfactory fired product. However, the wide variations in the properties of massive talcs have indicated the difficulties of obtaining satisfactory correlations of data necessary to establish a series of specific tests for accurate grading of samples of raw material. Such tests, therefore, were not developed. Although a detailed and thorough study of the physical and chemical properties of block talcs and their firing characteristics would certainly give better understanding of the whole problem of cracking and might result in a few simple tests and specifications that could be applied in the field to determine the suitability of a particular talc, such a study would be extensive and time-consuming, and the probability of obtaining the desired results is not great.

An actual controlled firing test on talc selected according to the obvious criteria of physical and chemical homogeneity and cut into pieces whose minimum dimension is greater than that expected to be used for the finished fired product is the only test that can be made at present to determine with certainty the suitability of the material for a specific need.

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REPORT OF INVESTIGATIONS

THE MICROSEISMIC METHOD OF PREDICTING
ROCK FAILURE IN UNDERGROUND MINING

PART II. LABORATORY EXPERIMENTS



BY

LEONARD OBERT AND WILBUR DUVALL

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BY

LEONARD OWEN, GEOLOGICAL ENGINEER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

THE MICROSEISMIC METHOD OF PREDICTING ROCK FAILURE IN UNDERGROUND MINING

Part II. - Laboratory Experiments^{1/}

By Leonard Obert^{2/} and Wilbur Duvall^{3/}

INTRODUCTION

This report is the second of four on the microseismic method of predicting rock failure in underground mining in which the results of a number of laboratory experiments designed to give information on the origin of microseisms (small-scale seismic disturbances) and microseismic properties of various mine rocks is presented. Part I of this report (Report of Investigations 3797) discussed the results of field experiments, the development of the microseismic method, the test procedure as applied to generalized problems, the method of analyzing microseismic data, and the conclusions that can be drawn therefrom. Part III will describe the application of the method to a number of specific mining problems investigated during the last 3 years, and part IV^{4/} will describe in detail the microseismic apparatus employed in the various phases of this work.

In the course of the development of this method and in applying it to mining problems there has always been some conjecture regarding the origin of microseisms. It was known from observations in many mines that microseisms originated in rock under pressure and that the microseismic rate - that is, the number of microseisms recorded per unit time - increased as the time of failure approached. It was also known that microseisms were produced at the time when the rock was visibly cracked or fractured; however, it was observed that the microseisms often preceded any indications of cracking or fracturing of recent origin. This raised the question: Did the microseisms unaccounted for by this cracking or fracturing originate by intermovements along fissures, seams, or fractures of geological origin, or did the microseisms originate in uniform pieces of homogeneous rock without occasioning any visible indications of failure? The answer to this question might have considerable significance when the application of the method to mining problems is considered. For example, if microseisms originate only along

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^{4/} These reports will be referred to hereafter as parts I, II, III, and IV.

seams, joints, fractures, etc., it would be impossible to employ the method in uniform homogeneous formations, whereas, if they do originate in homogeneous rock the method would have general application.

Part of this report discusses a series of laboratory experiments designed to give information on the origin of microseisms; the remainder is devoted to a study of the microseismic properties of various mine rocks. In the course of applying the method to a specific mining problem, a series of preliminary experiments has always been necessary to determine the microseismic properties of the rock. These preliminary experiments involved microseismic measurements in rock that was known to be under pressure and, wherever possible, following a sequence of mining that eventually led to an induced failure (such as that caused by the removal of pillars, remnants, timber, or other support). These preliminary experiments often were difficult to effect and always very time-consuming. It is the purpose of this part of the investigation to develop a laboratory method for determining the microseismic properties of rock that would replace at least part of the preliminary testing that heretofore had to be done in the mine.

ACKNOWLEDGMENT

The authors are indebted to Dr. Felix Chayes, chemist petrographer, Petrographic Unit, Eastern Region, Bureau of Mines, College Park, Md., for preparing the petrographic description.

TEST PROCEDURE AND RESULTS

Briefly, the test procedure employed in the first series of these experiments was as follows: A test specimen (type 1) was prepared from a rectangular prism of rock by drilling a hole parallel to the short axis of the prism through the center of one face. Figure 1 shows a number of these specimens. One of these rock specimens was then placed in a hydraulic press and a geophone inserted in the hole (as shown in fig. 2). The output of the geophone was supplied to a conventional microseismic recorder. An increment of load (usually 1,000, 2,000, or 4,000 pounds, depending on the estimated strength of the specimen) was applied to the specimen and the microseismic rate measured for a 4-minute period thereafter. This procedure was repeated for successive increments of load until the crushing strength of the specimen was reached. The purpose of this experiment was to show how the microseismic rate depends on the applied load.

Altogether 17 specimens of this type were prepared from various mine and quarried rocks. The specimens were sawed from the rough rock with a carbundum or a diamond saw, and the hole was drilled with a laboratory diamond drill made from a converted drill press. The dimensions of the specimens varied somewhat, depending on the size of the rock available. The average size was approximately 4 inches high, 2-1/2 inches wide, and 2 inches thick, and the diameter of the hole was approximately 1-1/2 inches. Care was used in selecting pieces of rock so that they were as nearly homogeneous as possible and free from cracks that might have been caused by blasting or handling

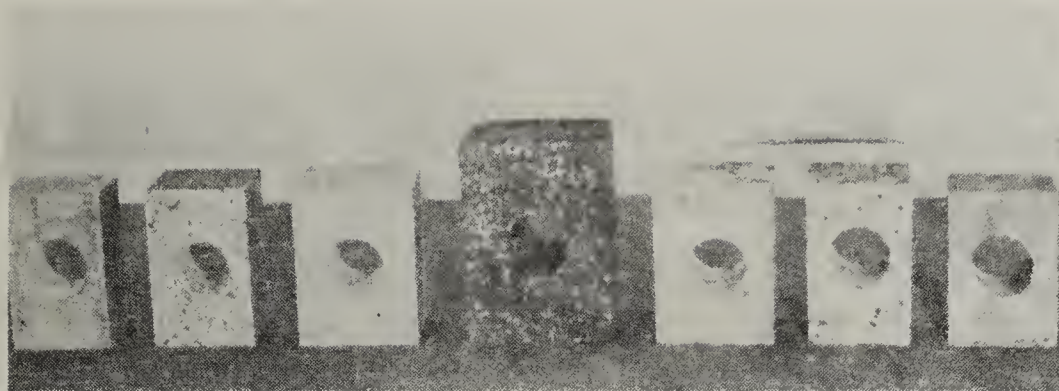


FIGURE 1.- Test specimens, type 1.

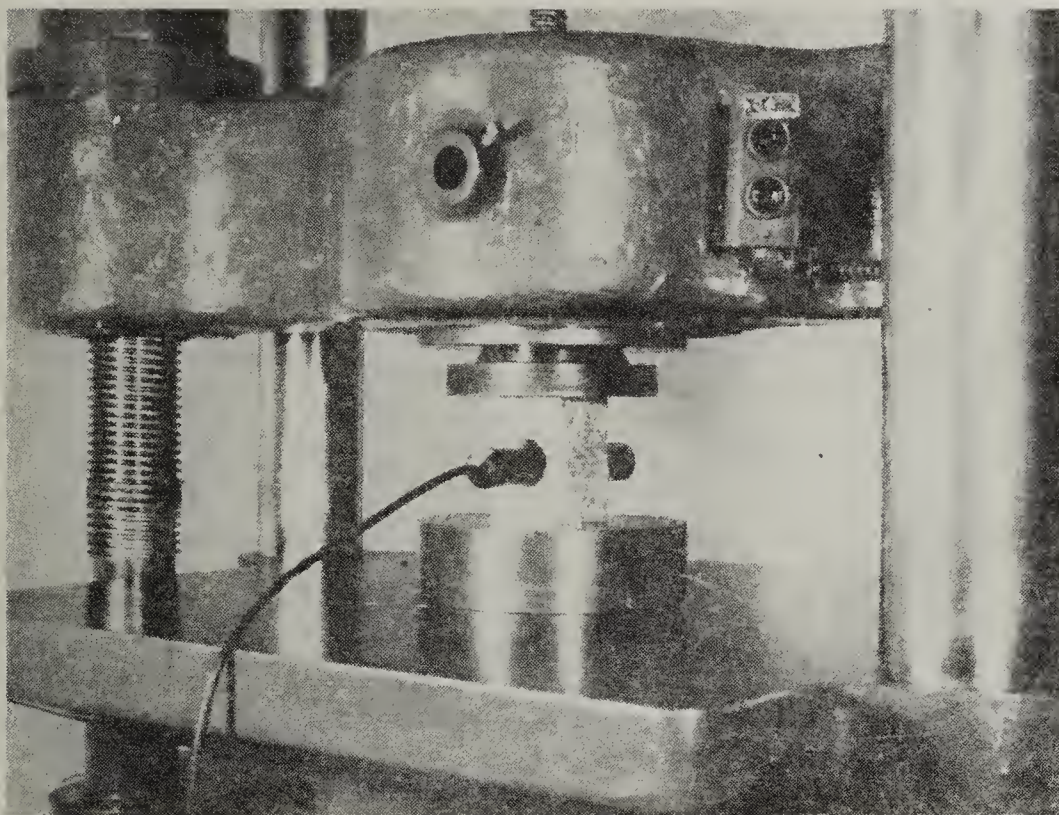


FIGURE 2.- Test specimens mounted in press.

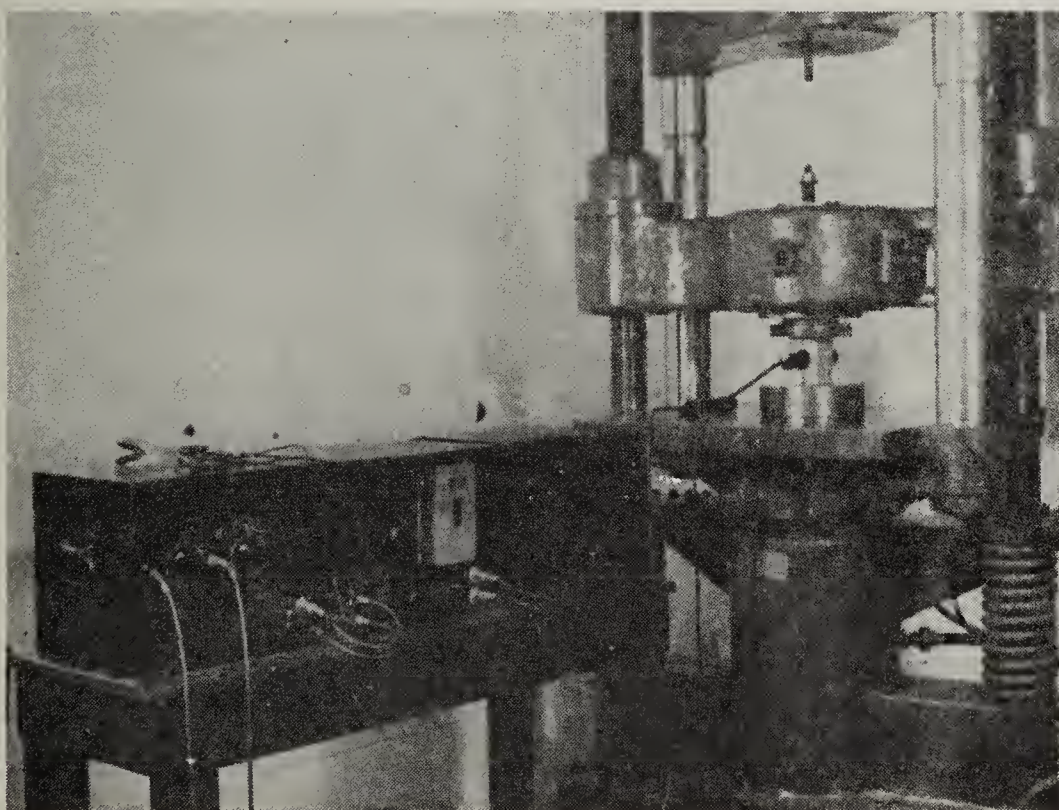


FIGURE 3.- Complete apparatus.

the rock and from fissures, joints, seams, etc., of geologic origin. The ends of the rock specimens were lapped so that the pressure distribution on these faces would be uniform when placed in the press.

The 1-1/8-inch-diameter core drilled from each of the specimens was sawed into two pieces 1-1/8 inches long. These pieces were prepared and tested as prescribed by the American Society for Testing Materials for determining the compression strength of the rock.

The rock specimen was mounted conventionally in the press using a spherical compression block on the upper surfaces (see fig. 2). A piece of blotting paper was placed on each end of the specimen to assist in equalizing the load over the surface. The blotting paper also helped to insulate the specimen from building vibrations transmitted through the press.

The testing machine was a 120,000-lb. hydraulic type provided with a special valve in the oil line supplying the hydraulic ram. When the load was applied to the specimen, this valve was closed and the hydraulic compressor shut off; otherwise the vibration from the compressor motor would obscure any other results. It was found that the load on the specimen could be sustained 15 minutes or more without decreasing appreciably.

The microseismic recorder and geophones were identical with the equipment used in all field investigations. No description of this equipment is given here, as it has been briefly described in part I and will be described in detail in part IV. The geophone inserted in the rock was connected to one channel of the recorder. This geophone recorded the microseismisms originating in the rock but also picked up an occasional man-made building vibration. To eliminate these man-made vibrations from the data, a second geophone was placed on the table of the press and connected to the second channel of the recorder. This geophone picked up all of the building vibrations that traveled through the press but was comparatively insensitive to the microseismisms originating in the rock. Thus, by comparing the two records it was possible to tell which were microseismisms and which were building vibrations. A photograph of the complete set-up is shown in figure 3.

During the recording periods an observer also listened to the amplified microseismisms (with the aid of earphones) and noted the character of the microseismisms, the microseismic properties of the rock, and other factors that are not indicated on the recording. Notes were also kept on any visible cracking that appeared in the specimen during the test and on any audible cracking.

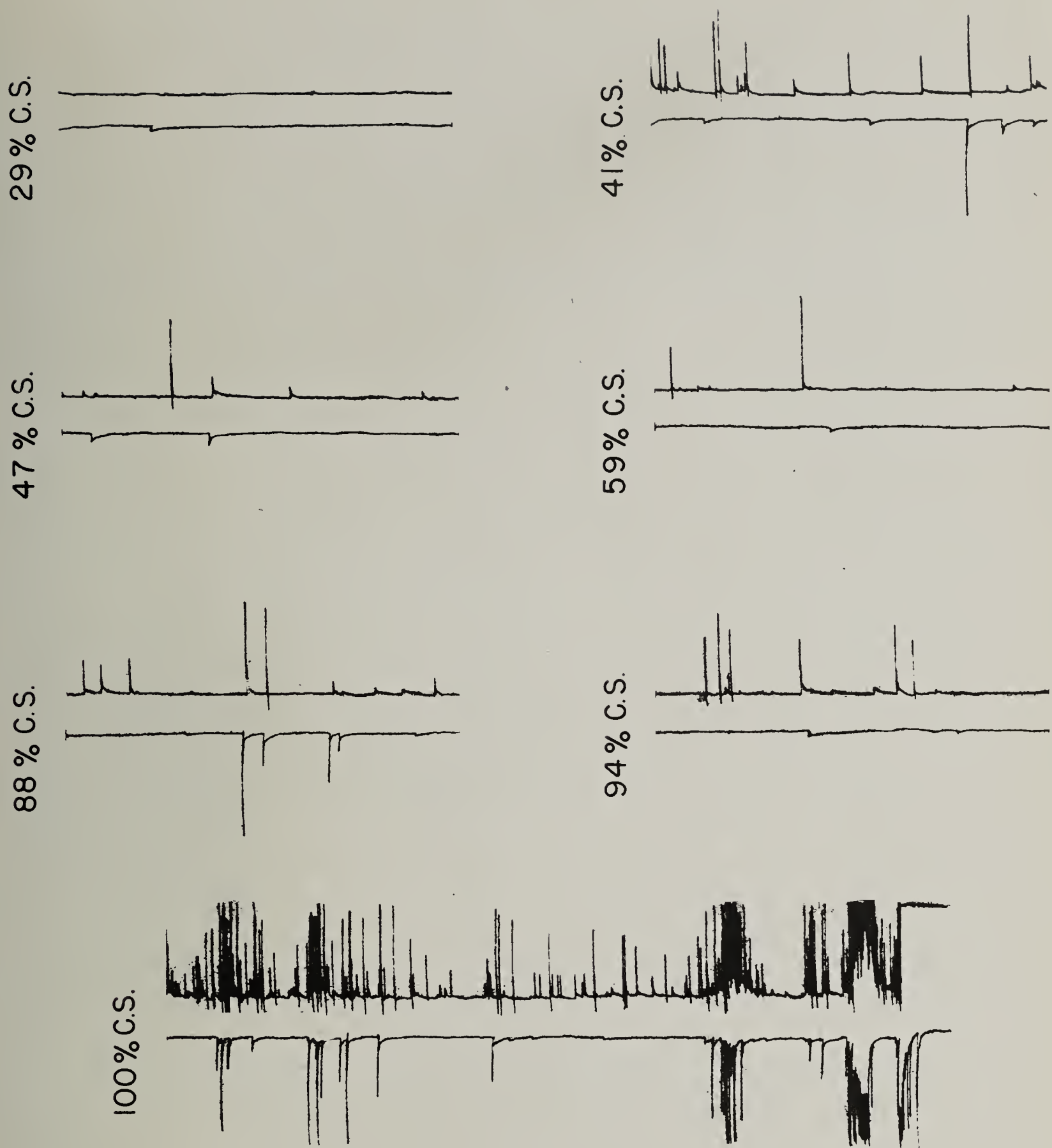
The amplifier gain was always set at the same value, except in a few instances when the microseismic rate was so high that the recorded microseismisms could not be resolved. In this case the amplifier gain was decreased to the point where satisfactory recording could be obtained. When these records were analyzed the microseismic rates were adjusted to compensate for this loss in amplification.

The microseismic records were analyzed as follows: The recorded microseisms were divided into two arbitrary classes, those having amplitudes less than or greater than one half the maximum recorded amplitude. The number of microseisms in each class was then counted for the first 3 minutes of each record - that is, for each increment of pressure. The total number of microseisms for 3 minutes was also obtained by adding the number in the large and small classes. A petrographic analysis of each of the various rock types was prepared from a study of fragments, polished surfaces, and thin sections. The petrography is summarized in appendix 1.

The data disclosed that all of the rock specimens showed the same general microseismic behavior. Briefly, this behavior was as follows: At a value of the load ranging between $1/8$ and $1/2$ of the crushing strength (c.s.^{5/}), depending on the specimen, a high microseismic rate was produced, which was always found to be associated with visible cracking. The cracks occurred in a vertical plane parallel to the axis of the hole and tended to split the specimen. At loads below the point where this cracking first occurred few microseisms were recorded. As the increments of load were increased above this point, the microseismic rate usually decreased rapidly until a minimum was reached somewhere between $1/2$ c.s. and $3/4$ c.s.

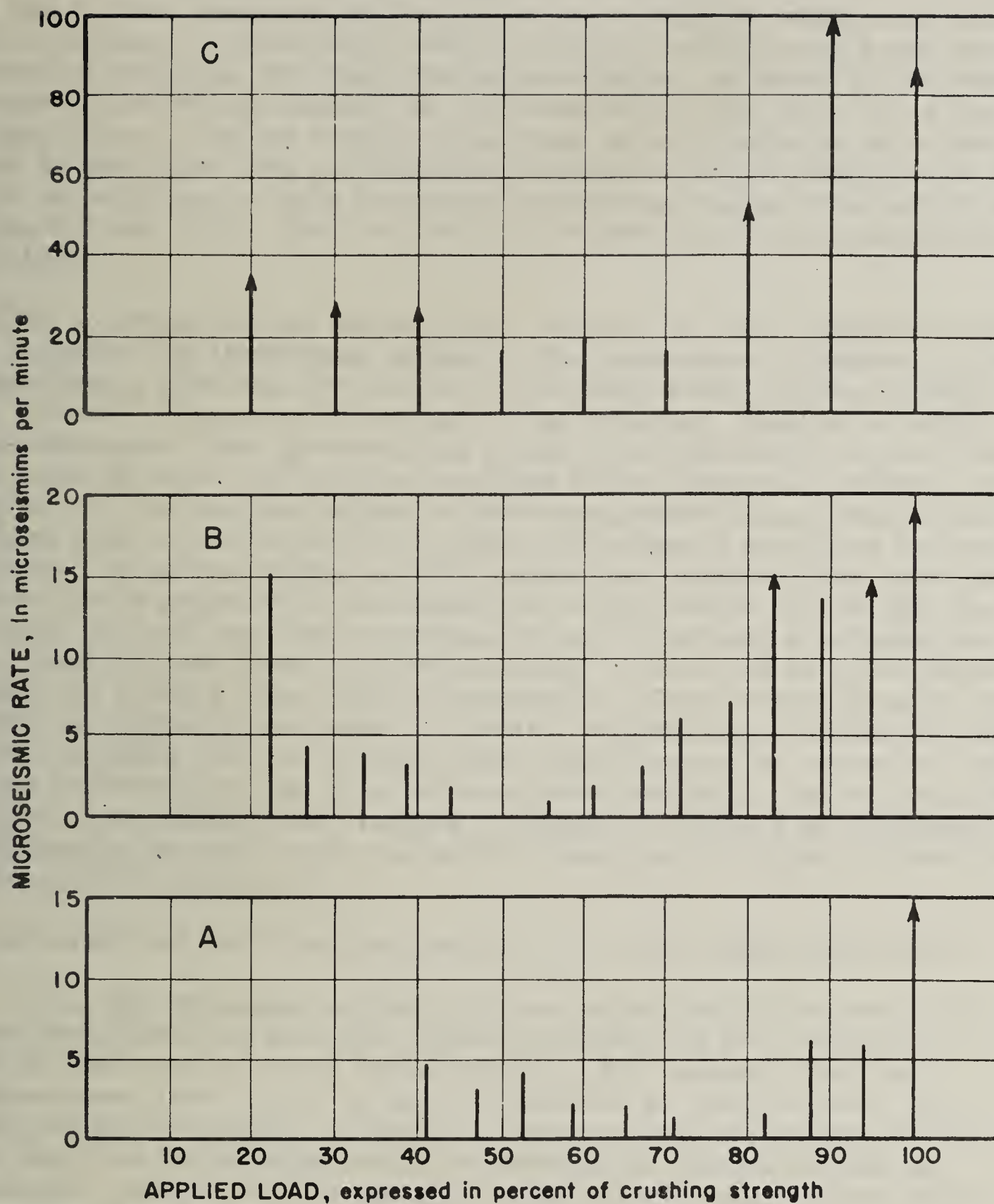
With further increases in the load the specimens divided into two groups: (1) Those that showed rapidly increasing microseismic rates between $8/10$ c.s. and the point where failure occurred and (2) those that showed comparatively little increase in the microseismic rate until a load had been reached where the failing process had actually started. Just before and during the course of the failing process, all specimens showed a comparatively high microseismic rate. However, rocks that showed rapid microseismic increase between $8/10$ c.s. and the point where they failed, failed abruptly, whereas specimens that showed comparatively little increase in the same range failed slowly. Although the process of failure is one of degree, the term "abrupt failure" is used to describe that condition in which the applied load decreased to zero in a second or less, whereas specimens described as failing slowly sometimes require as much as several minutes for the pressure to decrease to zero. The latter case also includes a few instances in which the load did not decrease to zero but dropped to some value substantially lower than the point where the load decrease first started. In many instances the abrupt failures were rapid enough to call violent, jarring the testing machine considerably, shattering the specimens, and throwing fragments around the room. In contrast, specimens that failed slowly went through a continuous crushing process that dropped the pressure slowly from a maximum value to one appreciably lower. The specimen was said to have failed when the specimen could not be loaded to a higher value.

^{5/} Hereafter, c.s. will be used to designate the crushing strength of the specimen. The crushing strength rather than the actual values of the applied load is given because the specimens were not all of the same dimensions; hence, no comparison could be made among the various numerical values of the load.



*Note: Upper track—Geophone in specimen;
Lower track—Geophone on table of press.*

Figure 4.—SECTIONS OF MICROSEISMIC RECORD FOR
DIFFERENT PERCENTAGES OF THE CRUSHING STRENGTH.
SPECIMEN 4 —GREENSTONE.



Note: Arrows indicate a part of the microseismic record could not be resolved, hence, the value is greater than that indicated.

Figure 5.- MICROSEISMIC RATE VS. LOAD FOR
 A-SPECIMEN 4, GREENSTONE;
 B-SPECIMEN 8, LIMESTONE;
 C-SPECIMEN 17, GRANITE.



THESE GRAPHS SHOW THE VARIATION OF THE
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 INCREASES AS THE AMPLITUDE
 OF THE OSCILLATIONS INCREASES.

In a few cases during the preliminary splitting (in the 1/8- to 1/2-c.s. range) and in most instances in the 8/10-c.s. to failure range a few audible reports were heard. Invariably, numerous audible reports were heard during the course of failure. The amplified microseisms, as heard in the earphones, were reported indistinguishable, in all respects but one, from those heard in field operations. The one exception was that no microseisms were heard that appeared to have come from a substantial distance (in field operations this distance estimate can be made because microseisms coming from distant points are of much lower pitch; that is, they do not have any strong, high-frequency components).

Table 1 summarizes the microseismic behavior of the 17 specimens tested. Column 1 states the identifying number of the specimens. Columns 2, 3, and 4, respectively, give the type of rock, the grain size, and the mineral habit. Column 5 lists the percentage of the crushing strength at which microseisms were first produced and column 6 the percentage of the crushing strength at which the vertical cracking first appeared. Column 7 states whether or not the specimen shows an increasing microseismic rate in the range 8/10 c.s. to the ultimate strength, and column 8 describes the type of failure. The microseismic activity, which was judged by the total number of microseisms produced by each specimen in the course of testing, has been arbitrarily divided into three classes. Class 1 included specimens that produced a total of less than 300 microseisms, class 2 300 to 1,000 microseisms, and class 3 over 1,000 microseisms. These classification numbers are given in column 9; the number of audible reports heard during the test in column 10 (this does not include those heard during the course of failure); the percentage of the total microseisms belonging to the large amplitude class in column 11; the crushing strength of the rock as determined from the compression strength tests heretofore described in column 12; and the specific gravity in column 13.

The results of the foregoing group of tests are summarized below:

1. All specimens produced microseisms during the course of the test; however, the total number produced and the pressure at which they were produced varied widely. For example, the four greenstones (Nos. 1, 4, 5, and 13) produced an average total of only 84 microseisms, of which a large proportion occurred either at the time the specimen split or immediately before and during failure. Representative sections of the microseismic record from specimen 4 are shown in figure 4, and the microseismic rate vs. the percentage of the crushing strength is shown graphically in figure 5a. In figure 4 each of the first six records covers 2-minute intervals and the 100-percent c.s. record 4-minutes. The upper track in these records, and all succeeding, is from the geophone placed in the specimen, and the lower track is from the geophone on the table of the press. It is to be noted that, of all the microseisms produced in the rock, only the more intense were picked up by the geophone on the table. The point where the specimen failed is indicated by the abrupt break at the end of the 100-percent c.s. record. Limestone specimens 8, 10, and 12 produced an average total of 390 microseisms which, except for the high

number produced at the time the specimens split, were distributed throughout the pressure range, increasing rapidly as failure was approached. Microseismic records from specimen 8 and the microseismic rate vs. load graph are shown in figures 6 and 5b, respectively. Each section of the record is for 2 minutes. The specimen failed at the point indicated by the large microseismic surge on the 100-percent c.s. record. Granite specimens 16 and 17 produced the greatest total number of microseisms, averaging well over a thousand (the exact number could not be determined owing to the inability, during parts of the test, to resolve the microseisms). The microseismic records for specimen 17 are shown in figure 7 and the microseismic rate-load graph in figure 4c. The first four sections of the record are for 2 minutes; the 80- and 90-percent c.s. records are for 3-1/2 minutes.

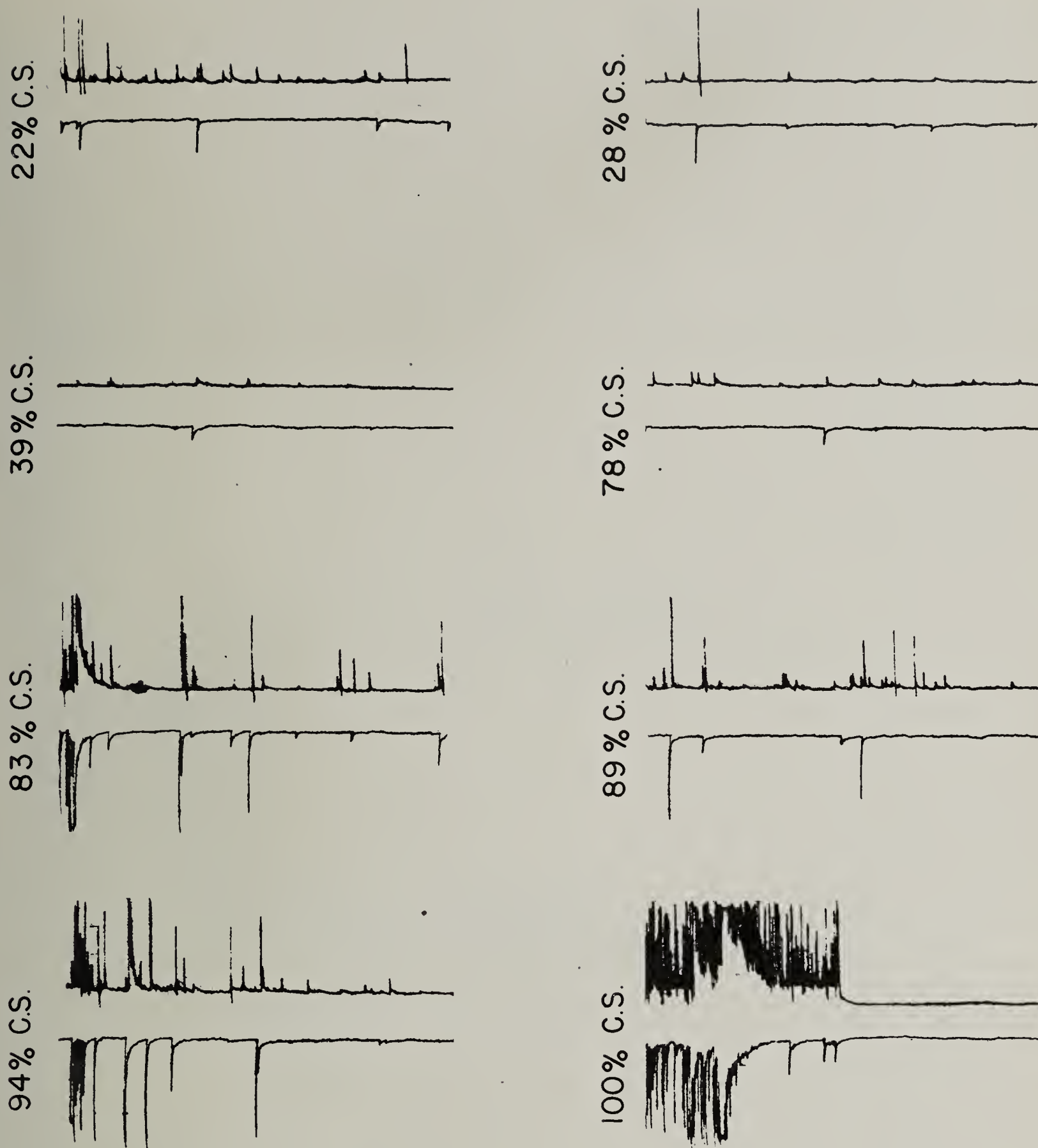
2. All specimens cracked at a load equal to approximately 1/2 c.s. or less and in a manner tending to split the specimen. This splitting is an inherent weakness in the specimen and can be eliminated by shaping the specimen differently, as will be shown later in the report. A high microseismic rate was produced during the course of this splitting, which usually decreased with additional increments of load until a minimum was reached somewhere between 1/2 and 3/4 c.s. The degree of splitting varied considerably from specimen to specimen, being most pronounced in the amygdaloidal basalt, No. 11.

3. All specimens produced a high microseismic rate during the course of failure, which was accompanied by audible cracking. In most instances after the actual failing process had started the microseismic rate was so high that the number of microseisms could not be counted.

From examination of the data in table 1, remembering that results are arranged in order of increasing microseismic activity, a number of correlations or trends are indicated:

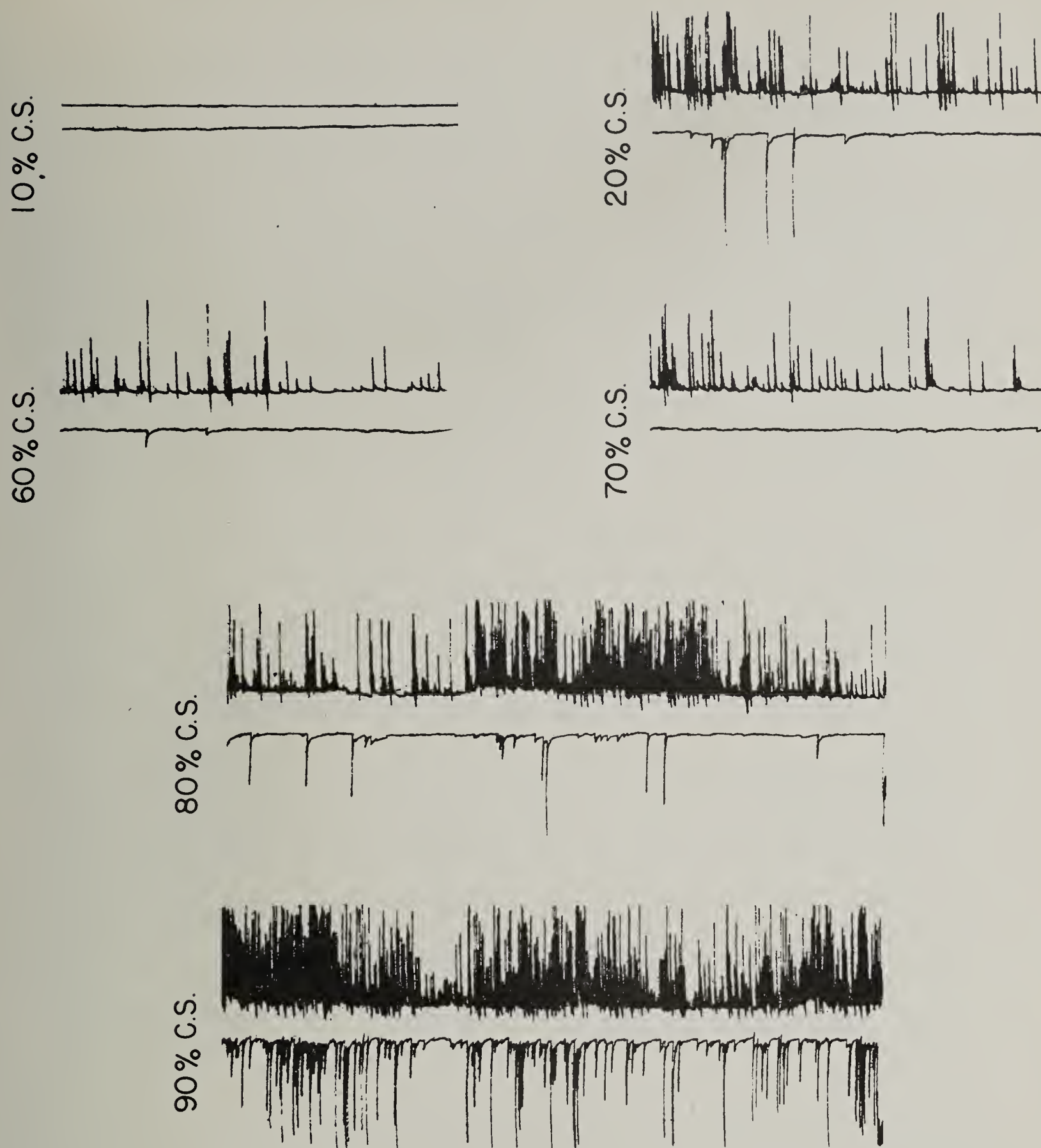
1. The specimens tend to group according to the type of rock, the groups being the four greenstones, the three limestones, and the two granites. With the three limestones and three or four of the greenstones this was probably due to the fact that the specimen came from the same geologic formation; however, the granite, epidosite, and one of the four greenstones specimens were of widely separated origins.

2. The specimens tend to arrange according to certain petrographic characteristics, namely, the grain size and the mineral habit. The grain size trends from fine to coarse and the mineral habit from flaky or acicular to granular. The amygdaloidal basalt, No. 11, was an exception. This basalt produced a relatively large microseismic total; however, the



*Note: Upper track - Geophone in specimen;
Lower track - Geophone on table of press.*

Figure 6. - SECTIONS OF MICROSEISMIC RECORD FOR
DIFFERENT PERCENTAGES OF THE CRUSHING STRENGTH.
SPECIMEN 8 - LIMESTONE.



*Note: Upper track - Geophone in Specimen;
Lower track - Geophone on table of press.*

Figure 7. - SECTIONS OF MICROSEISMIC RECORD FOR
DIFFERENT PERCENTAGES OF THE CRUSHING STRENGTH.
SPECIMEN 17 - GRANITE.

matrix was from glassy to microfine. The amygdules were granular and might have been responsible for the large microseismic production, but it is thought more likely that the brittle, friable nature of the rock was the principal cause.

3. The percentage of the crushing strength at which microseisms first occurred and the first visible cracking appeared (columns 5 and 6) both tend to show some grouping. The four greenstones and the hornstones all produced the first microseisms at the time the specimens split. Moreover, the percentage of the crushing strength at which this occurred was relatively high, being greater than 40 percent in every case. The chert and dolomite breccia both produced microseisms at 8 percent of the crushing strength and considerably in advance of the first visible signs of cracking. For the rest of the specimens these results were more or less random.

4. With one exception, the specimens that showed no increase in the microseismic rate in the range 8/10 c.s. to failure (column 7) were those that produced lowest (class 1) microseismic totals, whereas, all those that showed an increase produced high (class 2, class 3) totals. The one exception was the epidosite, No. 6, which showed no increase but produced a total of approximately 600 microseisms.

5. The type of failure exhibited by the specimen (column 8), with the exception of the chert breccia (No. 9) and amygdaloidal basalt (No. 11) divides into two groups, namely those that crush and those that shatter. The crushing group corresponds to the low microseismic rate group and the shatter group to the high microseismic rate group. Also, it is to be noted that there was a nearly 1-to-1 correspondence between the type of failure and the rocks which showed or did not show a microseismic increase prior to failure, the rocks which crushed showing no increase and the rocks which shattered showing an increase. Again the epidosite (No. 6) is an exception, as the microseismic rate did not increase in the high-pressure range.

No other trends or correlations are indicated between the microseismic production and the other physical properties, that is, the crushing strength, specific gravity, audible cracking, or percentage of large microseisms.

A second series of experiments was performed to study the effect of the rate-of-change of pressure on the production of microseisms. A second set of specimens was prepared (from the same rocks), each of which was as nearly identical as possible with the previous specimens. These specimens were mounted in the press in an identical manner, and the same microseismic equipment was employed. The testing procedure was as follows: A load was applied to the specimen equal to approximately half the ultimate strength of the specimen. A recording was then made for a period of 15 minutes (or less if the microseismic rate was zero). The load was then decreased to

one-fourth the ultimate strength. A recording was made during the time the load was decreasing and continued for a 15-minute period thereafter. The same procedure was repeated for loads equal to $3/4$, $1/4$, and $9/10$ of the ultimate strength of the specimen. Following the last recording the geophone was removed from the specimen and the load increased until the specimen failed.

Considered collectively, the microseismic behavior of the various specimens was as follows: When the load was raised to $1/2$ c.s., the vertical splitting previously described was observed. The microseismic rate was high during the start of the run but diminished to a comparatively low value, following which the rate tended to continue decreasing slowly through the 15-minute run; in fact, in some instances the rate diminished to approximately zero. When the load was decreased from $1/2$ to $1/4$ c.s., the recordings showed that microseisms were produced, usually at a high rate during the period while the load was decreasing, but when the load was held at $1/4$ c.s. the microseisms stopped almost instantly. When the load was increased from $1/4$ to $3/4$ c.s., no further cracking was observed. The microseismic rate was again comparatively high at first (in all cases higher than that measured during the corresponding part of the $1/2$ -c.s. run), diminishing quite rapidly, but to a level usually higher than that observed in the corresponding part of the $1/2$ -c.s. run. There was also less tendency for the rate to show further decrease; in fact, with many of the specimens the rate appeared to have reached a comparatively stable value. When the load was decreased from $3/4$ to $1/4$ c.s., microseisms were again produced during the period when the load was decreasing but stopped as soon as the pressure was held constant. The records taken as the load was raised to $9/10$ c.s. showed the same general behavior as with the $3/4$ -c.s. run, except that the average level was higher and more nearly constant. With some specimens the microseisms tended to come in sporadic bursts, and in a few instances additional cracking was observed at the time of these bursts. Following the $9/10$ -c.s. run the geophone was removed; and the load increased until the specimen failed, a procedure that was adopted to determine the crushing strength and the type of failure.

In summarizing the results of this test, it is evident that a part of the microseismic production is associated with the rate-of-change of the applied load and that the rate-of-change may be either negative (decreasing load) or positive (increasing load). The microseismic production associated with the decreasing load occurred only during the time the pressure was decreasing and stopped as soon as the load was held constant. Although no measurements could be made during the time the load was increasing the measurements made immediately thereafter showed a high microseismic level that decreased rapidly at first but more slowly as the run progressed. For loads above $3/4$ c.s., the microseismic rate usually became constant after 1 or 2 minutes; however, there was some tendency for the production to come in sporadic bursts. An example of this sporadic production is illustrated in the 100-percent c.s. run in figure 4.

TABLE 1

| Specimen number | Rock type | Grain size | Mineral habit | First micro-seisims, percent c.s.l. | First visible cracking, percent c.s.l. | Microseismic increase before failure | Type of failure | Total micro-seismic-class | Audible cracking | Large class microseisims, percent | Crushing strength, kg./cm. ² | Specific gravity |
|--------------------|---------------------|-----------------------------------|-----------------------------------|-------------------------------------|--|--------------------------------------|-----------------|---------------------------|------------------|-----------------------------------|---|------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 5 | Greenstone | Fine | Flaky or acicular | 66 | 66 | No | Slow crush | 1 | 3 | 40 | 37,700 | 2.74 |
| 1 | do. | do. | do. | 55 | 55 | No | do. | 1 | 0 | 20 | 25,300 | 2.89 |
| 4 | do. | do. | do. | 41 | 41 | No | Rapid crush | 1 | 3 | 26 | 36,300 | 2.71 |
| 13 | do. | do. | do. | 55 | 55 | No | do. | 1 | 0 | 30 | 38,400 | 2.88 |
| 15 | Hornstone | do. | do. | 41 | 41 | No | Crush | 1 | 0 | 16 | 18,600 | 2.87 |
| 3 | Schist | Medium to coarse | Flaky and granular | 25 | 33 | No | do. | 1 | 0 | 16 | 12,200 | 2.66 |
| 8 | Limestone | Fine to medium | Granular | 22 | 22 | Yes | Shatter | 2 | 1 | 11 | 30,400 | 2.90 |
| 10 | do. | Medium | do. | 10 | 26 | Yes | do. | 2 | 1 | 22 | 35,600 | 2.73 |
| 12 | do. | do. | do. | 10 | 16 | Yes | do. | 2 | 1 | 20 | 30,700 | 2.76 |
| 2 | Sandstone | Fine to medium | do. | 33 | 37 | Yes | Violent shatter | 2 | 2 | 26 | 27,900 | 2.63 |
| 6 | Epidoite | Medium | do. | 21 | 26 | No | do. | 2 | 0 | 26 | 50,600 | 3.16 |
| 14 | do. | do. | do. | 16 | 21 | Yes | do. | 3 | 4 | 17 | 51,900 | 3.07 |
| 7 | Dolomite Breccia | Medium to coarse, large fragments | Granular plus fragments | 8 | 16 | Yes | do. | 3 | 3 | 26 | 34,900 | 2.73 |
| 9 | Chert Breccia | Fine to coarse, large fragments | do. | 8 | 25 | Yes | Rapid crush | 3 | 2 | 14 | 16,500 | 2.81 |
| 11 | Amygdaloidal basalt | Matrix glassy large amygdules | Matrix glassy, amygdules granular | 16 | 25 | Yes | Crush | 3 | 4 | 30 | 25,000 | 2.62 |
| 16 | Granite | Coarse | Granular | 13 | 17 | Yes | Violent shatter | 3 | 0 | 30 | 41,700 | 2.65 |
| 17 | do. | do. | do. | 20 | 20 | Yes | do. | 3 | 2 | 33 | 45,600 | 2.63 |
| Crushing strength. | | | | | | | | | | | | |

| Specimen number | Rock type | Grain size | Mineral habit | First micro-seisims, percent c.s.l. | First visible cracking, percent c.s.l. | Microseismic increase before failure | Type of failure | Total micro-seismic-class | Audible cracking | Large class microseisims, percent | Crushing strength, kg./cm. ² | Specific gravity |
|--------------------|---------------------|-------------------------------|---------------|-------------------------------------|--|--------------------------------------|-----------------|---------------------------|------------------|-----------------------------------|---|------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 19 | Amygdaloidal basalt | Matrix glassy large amygdules | Matrix glassy | 75 | 100 | Yes | Shatter | 2 | 0 | 32 | - | - |
| 20 | Limestone | Medium | Granular | 27 | 100 | Yes | Slow crush | 2 | 0 | 19 | 28,900 | 2.72 |
| 21 | Epidoite | do. | do. | 48 | 95 | Yes | Violent shatter | 2 | 0 | 13 | 70,700 | 2.97 |
| 22 | Granite | Coarse | do. | 26 | 80 | Yes | do. | 3 | 11 | 25 | 45,600 | 2.63 |
| 23 | do. | do. | do. | 38 | 96 | Yes | do. | 3 | 4 | 29 | 45,600 | 2.63 |
| Crushing strength. | | | | | | | | | | | | |

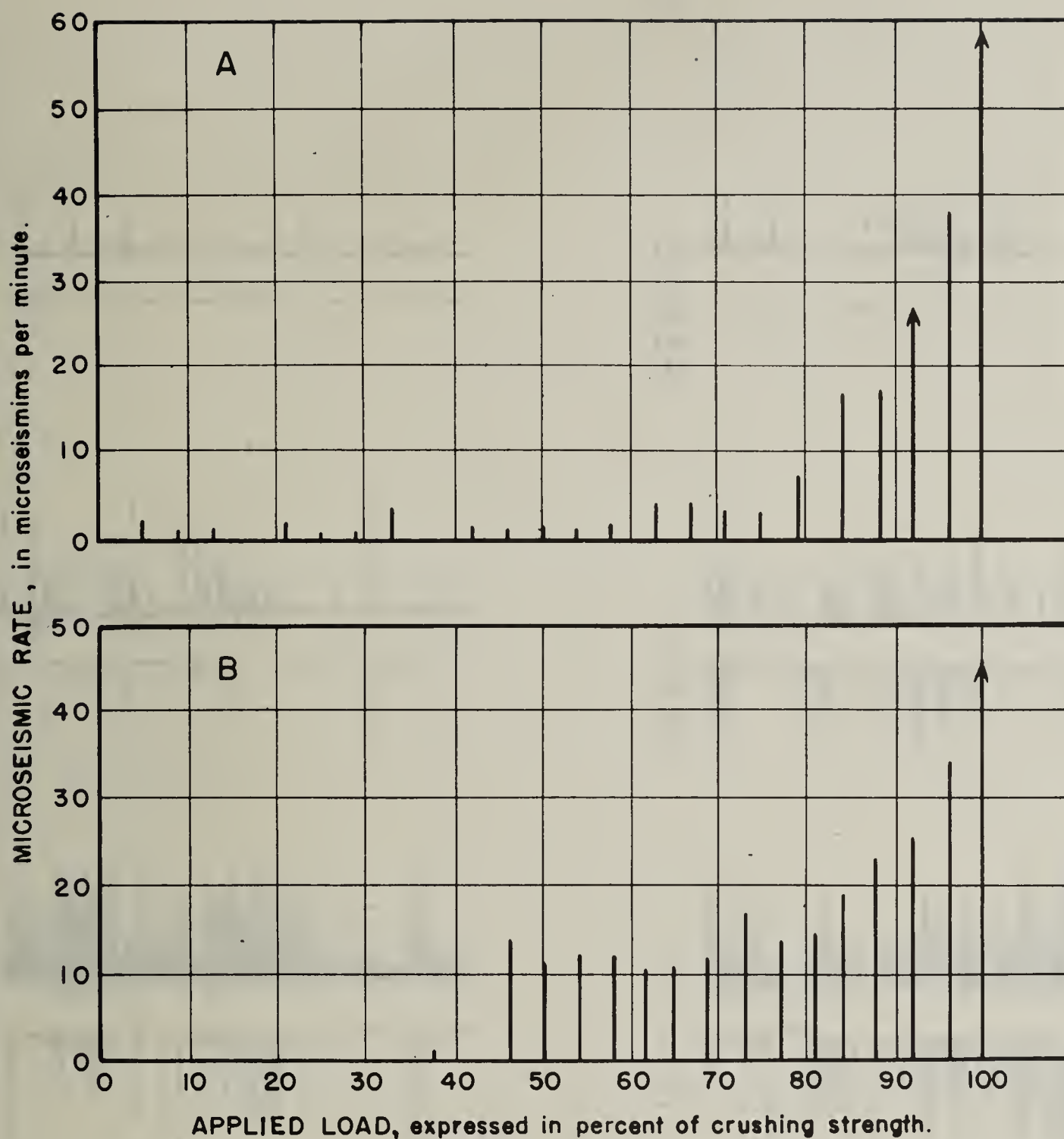
Owing to the fact that all the specimens tested in the foregoing tests split at a comparatively low value of the pressure, it was impossible to tell if the microseismic production, produced thereafter, originated in the solid rock or was caused by some intermovement along the surfaces of the cracks. Therefore, two tests were performed to give additional information on the origin of the microseisms. In the first of these a test specimen (No. 18) was prepared, identical with specimen 16, from the same piece of granite. This specimen was placed in the press and loaded at a rapid rate to a value estimated to be just below the ultimate strength of the specimen. The load was then reduced to a low value and the specimen examined. It was found that the vertical cracking had appeared in a pattern similar to that obtained when the load was applied in small increments. A geophone was then inserted and the specimen tested as described in the first series of experiments, that is, by loading the specimen in equal increments. The results of this test are shown graphically in figure 8a. Representative sections of the microseismic records are shown in figure 9. Each section of the record is for a 2-minute interval. The specimen failed at the end of the 100 percent c.s. run. Comparing the results from specimen 16 with those from specimen 18 it is apparent that in the former tests the high microseismic rate produced at 17 percent c.s. was caused by the splitting action alone, as this phenomenon is entirely lacking in the latter test.

The second test was designed to eliminate the splitting that occurred at low load values. This was effected by preparing the specimens (type 2) as shown in figure 10, eliminating the weakness inherent to the type 1 specimen caused by the center hole.

Three specimens were prepared from different types of mine rocks and two specimens from a piece of quarried granite. The tests of the specimens were like those in the first series of tests, that is, the specimens were loaded in small increments up to the point where the specimen failed.

The results of this series of tests are summarized in table 2. The tendency, shown in the former tests, for the specimens to split or crack in the low range was entirely removed by using the type 2 specimen. Correspondingly, there was no high microseismic production in the low load range. Instead, the microseismic production usually was found to increase with each successive increment of load, the increase being particularly pronounced in the 8/10- to 1.0-c.s. range. The results obtained from specimen 23 are shown graphically in figure 8b, and sections of the microseismic record are shown in figure 11. In the 100-percent c.s. run the geophone was removed from the specimen at the start, as it was apparent that the specimen was going to fail. This is indicated by the abrupt discontinuity in the upper track. The geophone on the table of the press continued to record throughout the run, and the specimen failed approximately 4 minutes after the run started.

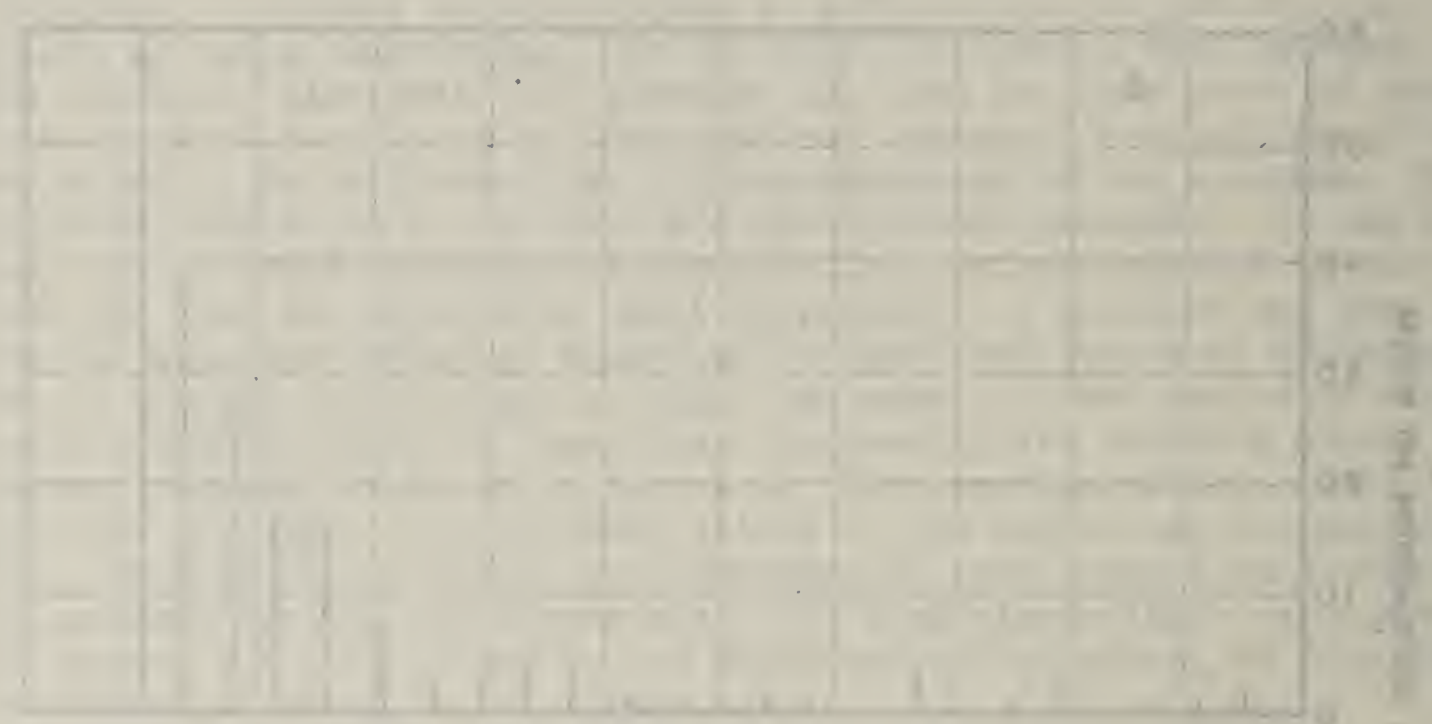
This series of tests demonstrates conclusively the microseisms can be produced in homogeneous rocks free from cracks, seams, fractures, etc., of either geologic or recent origin.



Note: Arrows indicate a part of the microseismic record could not be resolved, hence, the value is greater than that indicated.

Figure 8. - MICROSEISMIC RATE VS LOAD FOR
A - SPECIMEN 18,
B - SPECIMEN 23.

The following table shows the results of the analysis of the samples collected on the 10th of June 1964. The samples were collected from the same area as the samples collected on the 10th of June 1964. The results are given in the following table.

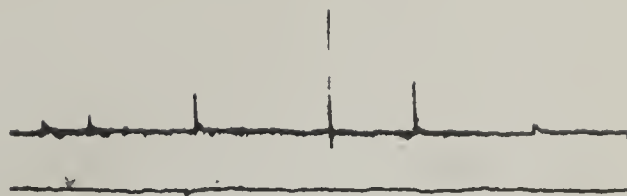


The following table shows the results of the analysis of the samples collected on the 10th of June 1964. The samples were collected from the same area as the samples collected on the 10th of June 1964. The results are given in the following table.

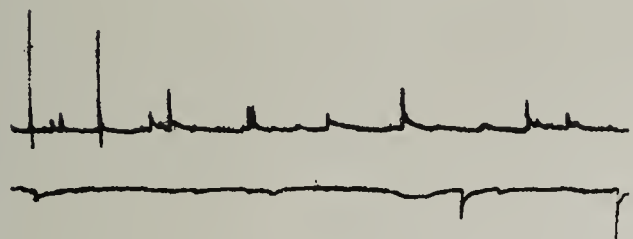
46% C.S.



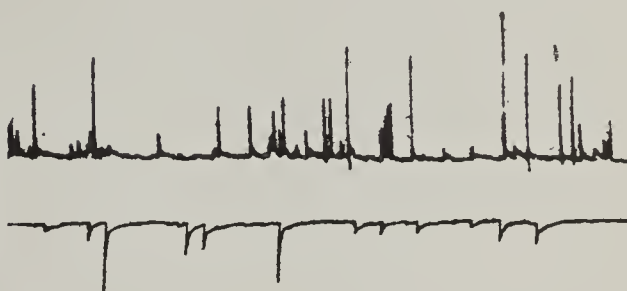
57% C.S.



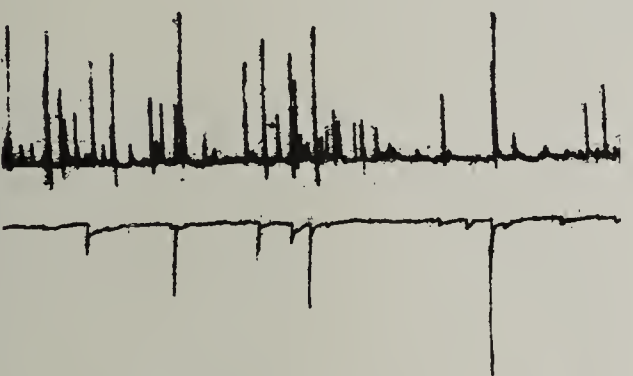
79% C.S.



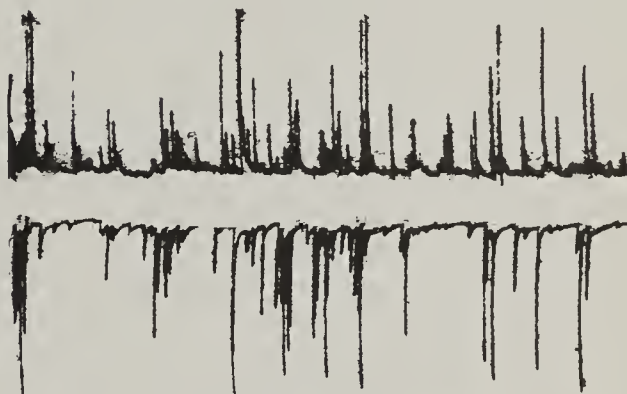
83% C.S.



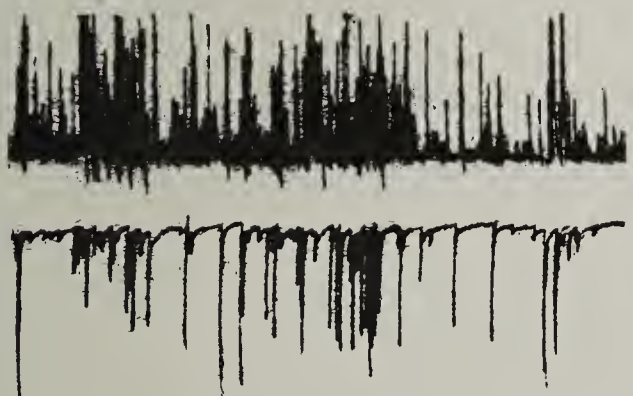
87% C.S.



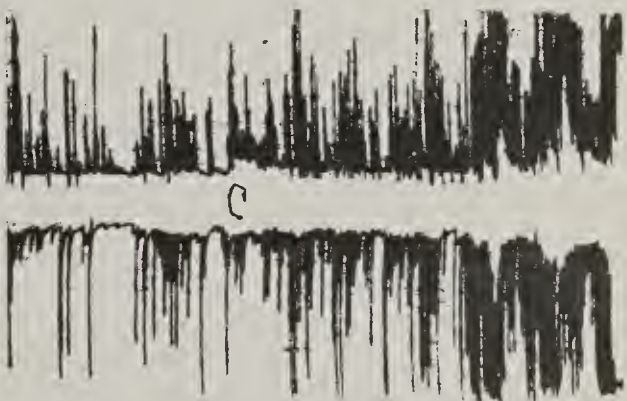
92% C.S.



96% C.S.



100% C.S.



*Note: Upper track-Geophone in specimen;
Lower track-Geophone on table of press.*

Figure 9.-SECTIONS OF MICROSEISMIC RECORD FOR
DIFFERENT PERCENTAGES OF THE CRUSHING STRENGTH.
SPECIMEN 18 - GRANITE.

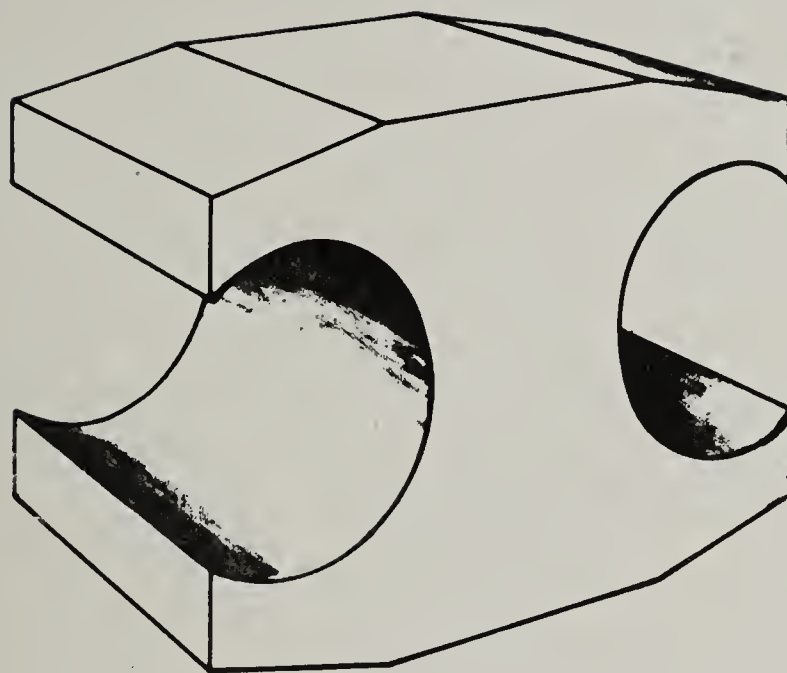
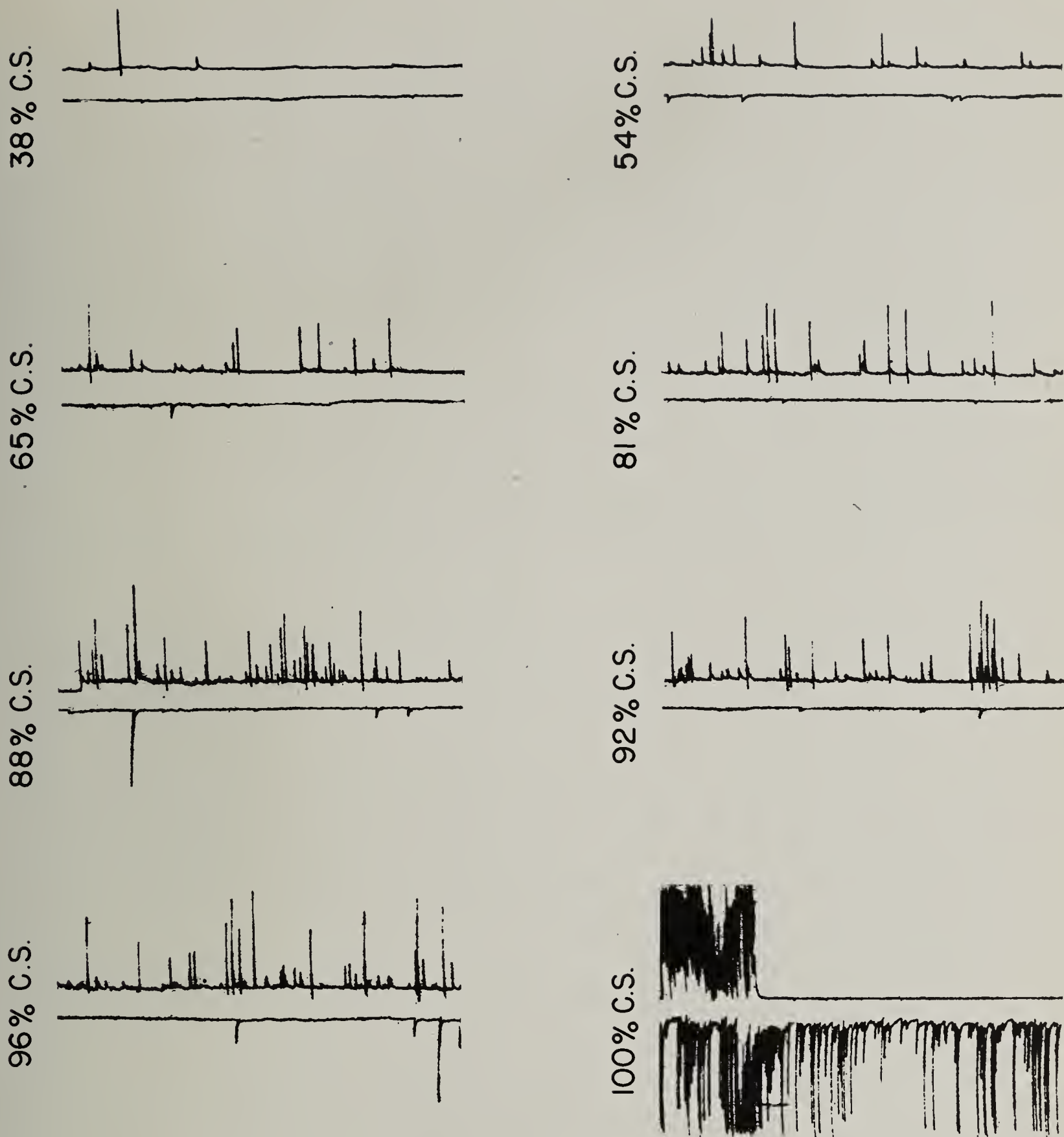


Figure 10.—TEST SPECIMEN — TYPE 2.



*Note: Upper track - Geophone in specimen;
Lower track - Geophone on table of press.*

Figure 11.-SECTIONS OF MICROSEISMIC RECORD FOR
DIFFERENT PERCENTAGES OF THE CRUSHING STRENGTH.
SPECIMEN 23 -GRANITE.

CONCLUSIONS

It has been demonstrated that, by placing a small rock specimen under pressure, microseismisms can be produced in the laboratory which, for all practical purposes, are identical with those recorded in actual mining investigations. The ability to produce these microseismisms in the laboratory has made it possible to study the various types of mine rock to determine their microseismic characteristics. Such an investigation was made on a number of mine rocks in which it was found that the microseismic production, that is, the total number of microseismisms produced in the course of compressing the rock to failure, varied widely. For example, the coarse-grained rocks, such as the granite, produced, on the average, over a thousand microseismisms, whereas the fine-grained rocks, such as the greenstones, produced less than 200. With two exceptions the rock types studied in this investigation were from mines in which no microseismic study had been made; therefore no correlations can be made with field operations. The two exceptions were the amygdaloidal basalt from Ahmeek, Mich., and the chert breccia from the Tri-State district, which were taken from mines in which microseismic tests had been conducted. These rocks were found to produce comparatively high microseismic rates in both laboratory and field operations.

The test showed that while the microseismic production depends largely upon the value of the applied pressure, at least part of the production is associated with the rate-of-change of pressure. This rate-of-change of pressure may be either negative (decreasing) or positive (increasing), but the effect is most pronounced for the latter.

The study of the various mine rocks showed that to some degree correlations can be made between the total microseismic production and the petrography or other characteristics of the rock. These correlations include such things as the increase in the total microseismic production with the grain size of the rock, the microseismic increase before failure, and the type of failure. These correlations point toward conclusions that could be used to good advantage in field operations, but it must be pointed out that the data from which they were obtained are, as yet, comparatively meager and are not considered adequate to serve as a basis for generalization.

These experiments also have demonstrated that microseismisms can be produced in homogeneous rock without any visible or audible evidences of failure. It was evident that microseismisms were also produced at the time the specimens cracked, but the results do not show whether or not microseismisms are produced by intermovements along the surfaces of such cracks or fractures once they are produced. It is reasonable to suppose that microseismisms do originate by such intermovements, as it is impossible to move one piece of rock over the surface of another, even when they are not under pressure, without producing some microseismisms. Thus, when the microseismic method is applied in mines that have rock formations with cracks or fractures (either of recent or geologic origin), some of the microseismisms probably originate in the homogeneous rock and some by surface intermovement. However, the above result shows that it would still be possible to employ the method in rock formations that were entirely devoid of these cracks and fractures, in fact, in rocks as uniform as those found in quarries.

The laboratory experiments described herein were performed after the field experiments described in part I and after application of the method described in part III. Although these experiments give considerable factual information on the origin of microseisms and on the microseismic behavior of rock, the results obtained therefrom in no way alter the conclusions that had been reached heretofore. Rather, these experiments confirm what was previously supposed or based on less definite evidence.

APPENDIX - PETROGRAPHIC DESCRIPTION OF TEST SPECIMENS

Specimen 1. Greenstone (Mt. Weather, Va.). This greenstone was a medium- to fine-grained amygdaloid which consisted principally of very fine-grain fibrous actinolite, with several percent each of epidote and leucoxene. The epidote occurred chiefly in angular grains, many of which seemed to be cleavage fragments. The leucoxene was about equally abundant as irregular aggregate patches or as fine specks disseminated through the actinolite and chlorite. The amygdules were flattened into wafer or disklike shapes and consisted solely of pale green chlorite.

Specimen 2. Sericitized sandstone. This sandstone consisted principally of rounded (0.05- to 0.15-mm.) quartz grains cemented by a very fine sericite aggregate. There were also a few large quartz grains and a little vein quartz, which contained skeletal sphene. The sericite replaced or filled cracks in the detrital quartz but was conspicuously absent in the vein quartz.

Specimen 3. Andalusite schist (Miami, Ariz.). A schist that contained occasional large crystals of colorless andalusite in a mixture of sericite, muscovite, and quartz. The margins and fractures in the andalusite were sericitized. Sawed surfaces usually were free of alteration; but the rock was somewhat weathered, and faces produced by hammer or wedge breaks may have been limonite-stained. The test specimens contained large lenses and veins of quartz. The schistosity was undulant but in places seemed nearly normal to the length of the specimen.

Specimen 4. Greenstone (Ely, Minn.). The matrix of this greenstone consisted of very fine-grained chlorite and leucoxene through which were distributed small needles and prisms of amphibole (probably alkaline). Calcite veinlets were common, lying mostly along the length of the specimens.

Specimen 5. Greenstone (Ely, Minn.). This greenstone was probably a duplicate of specimen 4 but seemed somewhat richer in vein calcite.

Specimen 6. Epidosite (Mt. Weather, Va.). This epidosite consisted principally of poikilitic epidote crystals with occasional veinlets, pockets, and amygdules of calcite and quartz.

Specimen 7. Dolomite breccia (Mascot, Tenn.). This dolomite breccia was a gray to tan medium-grained dolomite with irregular lenses and veins of coarse white dolomite. The latter was often the breccia matrix rather than the vein matter. The fine gray fragments often had shaly margins or partings, and there were occasional small, round quartz grains.

Specimen 8. Limestone (Bonneterre, Mo.). This limestone was fine- to medium grained, with a little glauconite and occasional (microscopic) chert nodules. This specimen was rich in galena (5-10 percent). The bedding was poorly defined.

Specimen 9. Chert breccia (Tri-State district). This chert breccia consisted of nearly equal parts of coarse-grained sphalerite and large chert fragments in a matrix of medium-grained dolomite. The rock was tight and nonporous for this area.

Specimen 10. Limestone (Bonneterre, Mo.). This limestone was an un-mineralized, uniform, homogeneous rock with bedding normal to length. There were numerous solution pits. Thin sections showed that the rock was partly recrystallized, the sedimentary calcite being fine-grained and the recrystallized carbonate coarse-grained.

Specimen 11. Amygdaloidal basalt (Ahmeek, Mich.). This basalt had a very fine-grained matrix which is virtually opaque due to hematite stain. The only identifiable mineral in the matrix was albite-oligoclase, which occurred in minute laths and prisms. There were numerous amygdules consisting of zeolites, epidote, and quartz (chiefly the latter) and many unfilled vesicles.

Specimen 12. - Limestone (Bonneterre, Mo.). This limestone was fine-grained and partly brecciated, with rounded grains of detrital quartz and patches of bright-green glauconite. There was also a few percent galena. The bedding was poorly defined, probably acutely inclined to length. The recrystallization was not as extensive as in specimen 10.

Specimen 13. Greenstone (Ely, Minn.). This greenstone consisted predominantly of chlorite with some albite-oligoclase and leucoxene, cut by veinlets of calcite and quartz.

Specimen 14. Epidosite, sheared and brecciated (Ely, Minn.). This epidosite consisted of angular fragments of epidosite and quartz-hematite intergrowth in a quartz matrix, where brecciated. Either parts of the rock were not brecciated or epidosite fragments were so large as to form most of specimen (probably the latter). There were also many minute quartz veinlets.

Specimen 15. Hornstone (Ely, Minn.). This hornstone was a fine-grained, randomly oriented mixture of green hornblende, quartz, and acid plagioclase, which showed the granular texture usually considered indicative of thermal metamorphism. A few quartz lenses, which may be filled vesicles, were shown in thin section. The rock was probably formed by reheating of a chilled lava. If the quartz lenses were not filled vesicles, there would be no way in which one could determine whether the original material was lava or shale.

Specimen 16. Granite (Quincy, Mass.). This granite was coarse-grained, with about 30 percent quartz, over 65 percent microperthite, and about 2 percent deep green hornblende. This rock was massive and unoriented, with no evidence of jointing or cracking.

Specimen 17. Granite (Rockport, Mass.). This granite was similar to specimen 16, but there was evidence of very mild crushing. The quartz showed undulant extinction, and the edges of feldspar crystals often were granulated.

Specimen 18. Granite, (Quincy, Mass.). This was indistinguishable from specimen 16.

Specimen 19. Amygdaloidal basalt (Ahmeek, Mich.). This specimen was similar to specimen 11, except that there was no open vesicles and the amygdules were filled with mixtures of calcite, epidote, and quartz in all proportions.

Specimen 20. Limestone (Bonnetterre, Mo.). This limestone consisted chiefly of medium-grained calcite rhombs; however, there was a band of much finer grained calcite 0.05 to 0.1 mm. along one edge. The contact between the medium and fine calcite areas was sharp. Detrital quartz grains and glauconite were found in both types.

Specimen 21. Epidosite (Ely, Minn.). This specimen was similar to specimen 14, except that there were a number of oval quartz-filled vesicles about 2 mm. in diameter. Blotchy, poikilitic aggregates of epidote about 2 mm. in diameter were concentrated about the amygdules.

Specimen 22. Granite (Rockport, Mass.). This was indistinguishable from specimen 17.

Specimen 23. Granite (Rockport, Mass.). This was indistinguishable from specimen 17.

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REPORT OF INVESTIGATIONS

SURVEY OF THE SUITABILITY OF DOMESTIC TALCS FOR HIGH-FREQUENCY INSULATORS



BY

THERON A. KLINEFELTER, SIDNEY SPEIL,
AND SIDNEY GOTTLIEB



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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

A SURVEY OF THE SUITABILITY OF DOMESTIC TALCS
FOR HIGH-FREQUENCY INSULATORS^{1/}

By Theron A. Klinefelter,^{2/} Sidney Speil,^{3/}
and Sidney Gottlieb^{4/}

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INTRODUCTION

The investigation of domestic talcs by the United States Department of the Interior, Bureau of Mines, was initiated in December 1941 at the request of Brig. Gen. Charles Hines of the United States Army. The urgency for such a study was expressed by General Hines as follows:

The radio-manufacturing industry has recently been expanded by the Army to provide sufficient capacity for defense needs, and considerable concern has been expressed by the Supply Arms and Services over maintaining continued availability of supplies of the necessary raw material. These ceramic products are used by the Signal Corps in all Army radio equipment, and to a greater degree in the new special ultra-high-frequency equipment. The Air Corps has recently become a user of large amounts of radio-grade ceramics for aircraft spark-plug covers required for high-altitude operations. In addition, the use of this material is essential to the proper functioning of the radio-navigation aids of the Civil Aeronautics Board.

Progress in the Bureau of Mines studies on talc was made available to representatives of the Army and Navy through frequent interim reports. Through the efforts of the several war agencies concerned with raw-materials supply and the domestic talc producers, the condition of scarcity that developed in 1942 passed to one of ease in 1943, and has so continued to date. Tentative estimate of reserves delineated indicates a supply of high-grade steatite sufficient to meet military war requirements for at least 4 or 5 years.

Basically, the Bureau of Mines studies took the form of a general survey of domestic talcs to determine those suitable for the production of radio ceramic or "steatite" insulators, in which specifications and requirements of the industry and the talcs in use by it were investigated. Certain standards were established by the study, and samples from the current and possible future producing areas were evaluated accordingly.

The Bureau of Mines Southern Experiment Station, Tuscaloosa, Ala., and the Electrotechnical Laboratory, Norris, Tenn., participated in the program. The former station was concerned primarily with the talc-beneficiation and other raw-material studies and the latter with the conduct of the ceramic body tests. The two studies, although coordinated, are presented as parts 1 and 2, respectively, in the publication.

ACKNOWLEDGMENTS

The investigation was conducted under the general supervision of Oliver C. Ralston, principal chemical engineer, until July 1, 1942, and subsequently under that of Paul M. Tyler, then eastern regional engineer. The earlier stages of the raw-material study were carried out by R. G. O'Meara, senior metallurgist; R. W. Smith, district engineer, District 5, Eastern Region; Glenn C. Truesdell, junior chemical engineer; and Sidney Gottlieb, associate mineral technologist, under the supervision of Will H. Coghill, supervising engineer, Southern Experiment Station, Bureau of Mines, Tuscaloosa, Ala. After July 1, 1942, the raw-material evaluation was carried on by T. A. Klinefelter, senior mineral technologist, and Sidney Gottlieb. The chemical analyses were made by Ellis E. Creitz, junior analytical chemist, and the petrographic analyses by Louis H. Berkelhamer, associate mineral technologist. The editorial advice of Alton Gabriel, chemist-petrographer, Eastern Experiment Station, College Park, Md., is greatly appreciated.

The project on the talc-body testing was conducted by Sidney Speil, non-metals engineer, under the direction of Hewitt Wilson, supervising engineer, Electrotechnical Laboratory. Bureau of Mines, Norris, Tenn. Ceramic, mechanical, and most of the dielectric tests were made at the Electrotechnical Laboratory. Final dielectric measurements were made by the Naval Research Laboratory.

The authors wish to thank Hans Thurnauer and the American Lava Corporation for making the early dielectric measurements and for continued advice and cooperation. The cooperation of the H. L. Crowley Co., West Orange, N. J., in loaning the Q meter is gratefully acknowledged. About 70 samples from Western States were furnished by members of the Federal Geological Survey, particularly Ben M. Page.

The majority of the material in parts 1 and 2 was included in a preliminary report, the circulation of which was restricted because of wartime necessity. Part 1 was written by T. A. Klinefelter and Sidney Gottlieb, and part 2 and a portion of the section on talc specifications in part 1 was written by Sidney Speil.

PART 1. - RAW MATERIALS

The majority of talc used for general purposes come from mines in the East, the annual output from St. Lawrence County, N. Y., constituting almost one-half of the total domestic production. Deposits are also worked in the Appalachian region from Vermont to Alabama. Most talcs produced in this region are not suitable for use in high-frequency insulators, as they are either too abrasive or contain too much iron oxide. Experiments with samples from several of the deposits show a possibility of obtaining products by beneficiation that would meet the requirements for high-frequency ceramics. The largest reserves of deposits of this type are in New York and Alabama.

In considering the Eastern States as a whole, the general impression is that the New York deposits would constitute the largest and most satisfactory reserves of talc if acceptable to the manufacturers. The Alabama deposit would be next, with an estimated tonnage of 300,000 to 500,000.^{5/} Some of the samples were within grade without beneficiation, but exploratory work will be necessary to determine the extent of this material. However, it would be unwise to consider any of the eastern deposits as usable reserves at present.

The deposits in the Western States are now supplying the required grade of material. In the past the material has come almost exclusively from the Talc City mine of the Sierra Talc Co., Inyo County, Calif. Other producers with mines in Inyo County are now supplying part of the market. With the Inyo County deposits should be included those of Esmeralda County, Nev., which are across the State line from Inyo County. The Sierra Talc Co. and others also obtain some of their talc from Montana and New Mexico.

^{5/} The Talc Deposits of Talladega County, Alabama. Lynn McMurtry, T.V.A., and Edgar Bowles, Geological Survey of Ala. Cir. 16, Geological Survey of Ala.

About 200 samples from 46 mines, 26 prospects, and 24 uncertain sources were examined in the Bureau's survey. Samples of a grade satisfactory without beneficiation were obtained from 17 mines and 5 prospects in the area included by Inyo and Esmeralda Counties. Samples from 5 of the larger mines were examined at the Norris Station, and all were rated as satisfactory. The talcs obtained from 2 mines in Montana (the Smith-Dillon and the Clark-Teutsch) were likewise of satisfactory grade.

If the assumption is made that the samples tested are fully representative of the respective deposits and that the estimates are reasonably correct, the reserves of satisfactory-grade material delineated are about 115,000 tons, or 4 to 5 years' supply at the present rate of consumption. As the samples were not obtained from exploratory drilling operations, tonnage estimates should be considered tentative. A greater tonnage can be inferred.

Definition of Steatite Talc

To the mineralogist the basic mineral is talc. Varieties of talc, based on structure, are "foliated," "fibrous," and "massive." The massive talcs have been called "steatite," "soapstone," or "pot stone," depending upon the degree of impurities present, steatite now being the purest commercial form, although it is usually not all talc. The Greek roots in the word "steatite" mean "soapstone," and most soapstones are quite impure. The foliated and fibrous types only are used for filler purposes in industry, and also in a number of ceramic bodies, including those for electric insulation. However, certain electric insulators are also made by machining and baking blocks of massive steatite.

Synthetic steatite mixtures made from the purer foliated talcs are not quite so good as insulators under certain operating conditions as those formed from the natural steatite. Hence, in the insulator trade the term steatite has become the standard of excellence, and the word "steatite" is used adjectively to designate a grade of talc suitable for making such bodies. So we have "steatite talc," "steatite ceramics," "steatite bodies," "steatite porcelains," when no actual steatite per se is present or included. The term "lava" is also used in a similar manner. Lava is a trade name used by one of the main producers of natural steatite products.

Talc Specifications

The first attempts to place limits on the impurities of talc were based on specifications submitted by manufacturers. Accordingly, the limits were set at 1 percent Fe_2O_3 and 1 percent CaO . Later these limits were modified to 1.5 percent of each substance, when a study of the talcs in use showed that these limits would more nearly conform to commercial shipments.

No standards for insulator-grade talc have been generally accepted. In the fall of 1942 the War Production Board froze the sale of talcs containing less than 1.5 percent CaO and less than 1.5 percent Fe_2O_3 on the assumption that they should be suitable for steatite-body manufacture. In general,

individual manufacturers of steatite ceramics have formulated their own standards, which range from 0.6 to 1.0 percent lime and 0.1 to 1.5 percent Fe_2O_3 . Despite these chemical limitations, some manufacturers add lime to their bodies, use blends of pure talc and high-lime talc, or in other ways apparently disregard their own standards. One commercial talc contains 5.4 percent lime. The imposed limitations have resulted from unsatisfactory experiences in maintaining uniformity of shipments of talc containing variable amounts of calcium-bearing compounds. The most commonly used California talc contains approximately 1 percent Fe_2O_3 ; yet a talc with 0.8 percent Fe_2O_3 was rejected by a steatite producer because of its high content of iron oxide. Another sample containing 2 percent Fe_2O_3 was judged satisfactory by a different company.

Talc must be not only within certain limits chemically but must also possess the proper physical properties to fit the common manufacturing processes. Finally, it must give a fired body that satisfies definite electrical and mechanical requirements. One objection to setting the same limits for all talcs is the commercial practice of mixing talcs of different characteristics. Thus, a talc of high shrinkage may be mixed with one of lower shrinkage in proportions that will produce an intermediate shrinkage. Either one of the talcs might be unsatisfactory when used alone. Definite limits under such circumstances are difficult to set. Many data from the manufacturers will be necessary before satisfactory specifications can be adopted.

The following specifications were used in the evaluation of the raw material:

Fe_2O_3 , maximum limit 1.5 percent; to be determined by assay.
 CaO , maximum limit 1.5 percent; to be determined by assay.
 Al_2O_3 , maximum limit 4.0 percent; to be determined by assay.

The total of all nontalc minerals should not exceed 5 to 10 percent, and preferably should not be more than 1 to 2 percent; to be determined by microscopic examination or by flotation.

After heat treatment for 1 hour at $2,300^\circ\text{F}$., the color should not be darker than that of the standard California talc treated under similar conditions.

The talc should show no more loss in an abrasion test than the standard California talc.

If some of these limits are exceeded slightly the talc may be recommended as a blend.

Sample Manufacturer's Specification

For purposes of comparison, the following specification, used by a manufacturer of steatite ceramics, is one of the best available:

Specifications for Powdered Ceramic Talc for
Steatite Insulator Manufacture

1. The talc shall be massive and soft, substantially free from foliated, flaky, and fibrous crystals. It shall be free from gangue which makes a dark color in kilning and produces dark spots or specks in the ware.
2. It shall be ground to such particle size that at least 95 percent passes a 325-mesh screen (43 microns) and 99 percent passes a 200-mesh screen (74 microns).
3. The color of the talc in the unfired state is of no importance; however, it is important that the material, after being heated to approximately $1,350^{\circ}\text{C}$. ($2,462^{\circ}\text{F}$.) in an oxidizing or neutral atmosphere, has a uniformly cream-to-white color.
4. The theoretical chemical analysis of talc ($3\text{MgO}\cdot 4\text{SiO}_2\cdot \text{H}_2\text{O}$) is:

| | |
|------------------------|--------------|
| MgO | 31.9 percent |
| SiO ₂ | 63.4 percent |
| H ₂ O | 4.7 percent |

It is desirable that this analysis be approached as closely as possible. The following analysis gives the limits of impurities permissible:

| | |
|---|---------------------------|
| SiO ₂ | Not less than 60 percent |
| MgO | Not less than 30 percent |
| Al ₂ O ₃ | Not more than 2.5 percent |
| CaO | Not more than 1.0 percent |
| Fe ₂ O ₃ | Not more than 1.5 percent |
| Na ₂ O plus K ₂ O | Not more than 0.4 percent |
| Loss on ignition .. | Not more than 6.0 percent |
| Acid soluble lime... | Not more than 1.0 percent |

A very important factor for the supply of steatite ceramic talc is its uniformity from one shipment to another, so that the permitted deviation between shipments should also be specified.

5. The powdered material shall be packed in paper bags or paper-lined bags of 50-lb. or 100-lb. units.
6. In submitting samples for test, a representative 1-pound sample, pulverized, together with a small nugget of the crude material, is satisfactory. If test shows promise, a 100-pound sample will be required. Chemical analysis, if available, should accompany offers. Brokers must disclose the country or place of origin before confidence can be placed in new sources.

This specification stresses uniformity of shipments but establishes no limits as to permissible deviations. Item 6 indicates that the foregoing standard is a qualifying one rather than a positive specification. Any talc that satisfies the preliminary conditions is suitable for a test in the production line but a talc that satisfies the chemical specifications may still be rejected in the production test on account of shrinkage or other physical or mineralogical characteristics. Experience indicates the lack of complete coordination between chemical oxide analyses and production requirements.

Physical Properties

Iron oxide is the principal cause of color changes, and higher percentages lower the dielectric efficiency. Lime has been shown to improve the dielectric properties^{6/} by some investigators. High-lime talcs containing either CaCO_3 or tremolite (calcium magnesium silicate) often have a high shrinkage and usually a shorter vitrification range than the pure talcs. High-tremolite-bearing talcs are very abrasive and therefore would be undesirable except as blend talcs. Although high lime content may serve as an index of impurities in the talc and indicate that it is unsuitable for use alone, it is not sufficient to reject it for use as a blend if the lime-bearing mineral is well-disseminated through the talc.

Firing shrinkage also depends on the fineness of grinding. Observations in the course of another investigation have shown that fine grinding may increase the shrinkage as much as 4 percent and lower the firing temperature as much as 15°C . Screen tests alone would not be adequate to determine the particle-size distribution, and some form of size analysis in the subsieve range would be desirable.

Each manufacturer prepares a body composition that, after firing to a given temperature on a given schedule, produces definite, important physical properties, including shrinkage, absorption, and power factor. Any variation in the shrinkage would necessitate scrapping the manufacturers' stock of steel dies. Variations in other properties may not be as harmful, but they would necessitate changes in plant operation. The final test of a talc is the direct substitution for the commercial talc in use and a comparison of the properties of the new body with those of the established standard body. No matter how well a talc meets other specifications, this is the final test applied by an operating factory. One method recommended by a leading manufacturer is determination of the green-density versus fired-volume-shrinkage relation for the talc being used. Any other talc that satisfies this relation within production limits is usually a practical substitute.

Testing Methods

The final results of the raw-material tests made are given in table 2, in the form of ratings. The ratings are based on a combined consideration of the various tests; no single evaluation is used as a criterion. The various examinations and tests are as follows:

^{6/} Thurnauer, Hans, Review of Ceramic Materials for High Frequency Insulation: Jour. Am. Ceram. Soc., vol. 20, 1937, pp. 368-372.

1. Sample. - Crude, unground material was preferred by the Bureau of Mines. Because the main market for talc is for filler purposes, most talc is marketed dry-ground to 325-mesh. Much coarser sizes are preferred for microscopic examination.

The crude sample was crushed to about 20-mesh, riffled, and sampled for the various tests. If the sample was to be used for body tests, it was ground to 325-mesh. If flotation was necessary, it was first wet-ground to 200-mesh, then beneficiated by flotation, and the concentrate was finally dried and ground to 325-mesh.

2. Petrographic Examination. - This examination was made to determine roughly the amount, kind, and distribution of impurities. Although not an absolute necessity, this test often saved time.

3. Chemical Assay. - Routine assays were made for iron oxide and lime, and for alumina where the petrographic examination had shown a relatively large amount of alumina-bearing minerals, such as chlorite, clay, or soil.

4. Flotation. - If the analysis showed that either the iron oxide or lime impurities exceeded the 1.5-percent limits, flotation tests were made to reject any minerals containing them.

5. Color. - These tests were made by heat-treating small plaques at 2,300° F. for 1 hour. The color should not be darker than that of standard California talc that had received similar treatment. The fired plaque could be tested to give a rough idea of shrinkage and absorption.

6. Abrasion. - Losses of a standard metal surface due to abrasion were determined on a machine developed for evaluating dentifrices.^{7/} Although the abrasive characteristics are considered important by the manufacturers, they have not formulated any definite limits for this property in their specifications. The abrasion losses, unless excessive, were not used in final ratings.

A detailed discussion of the methods of raw material testing in the laboratory and field will be found in the appendix to part 1.

Discussion of Results

Approximately 200 samples from locations given in table 1 were examined at the Southern Experiment Station. Samples that were satisfactory or could be made so by beneficiation, when known to be representative of large deposits, were prepared and sent to the Electrotechnical Laboratory of the Bureau at Norris, Tenn., for further testing in a standard body. The detailed results of the Norris Station tests will be found in part 2 of this report.

Some samples show a difference in the two ratings. For example, of 17 samples that the Tuscaloosa Station rated satisfactory (S in table 2), 5 were

^{7/} Smith, Ralph W., Machine for Testing Dentifrice Abrasion: Ind. and Eng. Chem., vol. 12, July 15, 1940, p. 419.

found by the Norris Station to be refractory; and of 15 additional samples that were satisfactory when beneficiated, ~~6~~ were refractory. The reason for this diversity is apparent when the iron and lime contents are compared with those of the standard talc used in the standard body. The standard talc, 1-A, contains 1.26 percent Fe_2O_3 and 0.62 percent CaO , or almost 2 percent combined oxides. These impurities act as a flux during heat treatment and cause greater vitrification. With two exceptions, all assays of those talcs marked "refractory" by the Norris Station show that either or both iron and lime are lower in content than the standard 1-A talc. In short, these talcs are really purer than the standard and need additional fluxes or other adjustments of body composition or they may be used as blends. To restrict the survey to talcs that carry the same amounts of fluxes or impurities as the standard would limit the potential reserves. Hence, it was considered best to include the purer talcs as satisfactory on the basis of tests on the raw material.

The results of beneficiation show that the lime content in many of the samples may be satisfactorily reduced by flotation. However, very little can be done to reduce the iron content. An exception is the talc from the Appalachian deposits, which usually contains iron in the form of magnetite. Several experiments with Appalachian talcs showed that a portion of the magnetite may be removed by magnetic separation and that flotation would remove an equal amount of iron (probably the same free magnetite particles). The assays listed as "flotation concentrate" (marked C in table 2) indicate the relative amount of iron likely to be removed by either process. The weight percent of easily recoverable talc is given in table 2.

The body work at the Norris Station indicates that an iron oxide content in excess of 2 percent has a deleterious effect on certain electrical properties. Assays for iron show that more than 1.5 percent Fe_2O_3 produces a color usually darker than the standard. Occasionally a lower content will result in a darker color, but a complete analysis probably would reveal other coloring oxides. The chosen limit of 1.5 percent iron oxide may be assumed to be satisfactory, particularly with respect to color.

The limit for lime content is not as well-defined. In the preliminary testing of the raw material, a sample with a given lime content fired in the usual manner might border on fusion, whereas another with an even higher content would appear much more refractory. The tendency toward refractoriness was much more noticeable in the New York talcs than in the West coast talcs. The petrographic analyses show that if the lime assays are about the same, tremolite is the chief impurity in the more refractory talcs, and calcium carbonate is usually the main impurity in those tending to overfire. The work at Norris partly confirms this fact. For instance, 8-J, a New York talc containing 6.02 percent CaO originating from tremolite, was reported by the Norris Laboratory to be refractory. On the other hand, 38-D, a California talc with a lime content of 2.78 percent originating from carbonates, overfired. It is apparent that an unqualified universal limit on lime will not be satisfactory; however, for the West coast talcs, the limit is accurate enough for all practical purposes. There is also some question about the alumina tolerance. Most of the acceptable brands of talc carry between 1 and 2 percent Al_2O_3 . The 4-percent limit often allowed is thought to be liberal.

The data on abrasion need correlation with those of the industry to make the evaluations of maximum value. Results from the "wear-out" of a number of industrial dies are necessary for correlations. The table shows that in general the talcs from the Western States and those along the Appalachian line are all as soft or softer than the standard. This generalization does not include the Gouverneur talc district, St. Lawrence County, N. Y., which lies west of the Appalachian line.

TABLE 1. - Finding list of talc samples (Numerical order)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|----------|--------------|
| | | County | State | |
| 1- | Sierra Talc Co., 428 Union Bldg., Los Angeles, Calif. | | | |
| A | Standard #6 | Inyo? | Calif. | Mfr. |
| B | Sierramic | do. | do. | Producer |
| C | White Mountain | do. | do. | Do. |
| D | Lenbeck | do. | do. | Do. |
| E | Isolantite or high grade | do. | do. | Do. |
| F | Dump #9-Talc City mine | Inyo | do. | USGS |
| G | Dump #3- do. | do. | do. | Do. |
| H | B Level- do. | do. | do. | Do. |
| I | Dump #15- do. | do. | do. | Do. |
| J | Adit dump-Warm Spring mine | do. | do. | Do. |
| K | Adit-Talc City mine | do. | do. | Do. |
| L | Cross cut- do. | do. | do. | Do. |
| M | Mill sample-Oasis mine | Esmeralda | Nevada | Do. |
| N | Dark Talc-Alliance mine | Inyo | Calif. | Do. |
| O | Run-of-mine (large sample of 1-M)-Oasis mine | Esmeralda | Nevada | Owners |
| P | Run-of-mine-(1-M)-Oasis mine | do. | do. | Do. |
| R | -- - Florence mine | Inyo | Calif. | USGS |
| S | Tim's drift-White Mountain mine .. | do. | do. | Do. |
| T | Glory hole- do. | do. | do. | Do. |
| U | Adit-Frisco shaft | do. | do. | Do. |
| 2- | Southern Talc Co., Grant Bldg., Atlanta, Ga. | | | |
| A | Roofing talc-#200-Mine at Chatsworth, Ga. | Murray | Georgia | Producer |
| B | Serpentine-Verde Antique Quarry-Georgia Marble Co. Tate, Ga. | Cherokee | do. | Do. |
| C | do. | do. | do. | GaGS |
| 3- | Cohutta Talc Co., Dalton, Ga. | | | |
| A | 31X Air-floated- mine near Chatsworth, Ga. | Murray | do. | Producer |
| 4- | Carbola Chemical Co., Natural Bridge, N. Y. | | | |
| A | Microvelva "A" | Lewis | New York | Do. |
| B | #28 | do. | do. | Do. |

TABLE 1. - Finding list of talc samples (Numerical order) (Cont'd.)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|----------|--------------|
| | | County | State | |
| 5- | Bull Run Talc Co., 474 Fairfax Rd., Drexel Hill, Pa. | | | |
| A | Foundry grade | Fairfax | Virginia | Producer |
| 6- | Hitchcock Corporation, P. O. Box 20, Asheville, N. C. | | | |
| A | Crayon grade-mine at Murphy, N. C. | Cherokee | N. C. | Do. |
| B | South drift- do. | do. | do. | BM |
| C | North drift- do. | do. | do. | Do. |
| 7- | Vermont Mineral Products Co., Chester, Vt. | | | |
| A | Ground talc | Windsor | Vermont | Producer |
| 8- | W. H. Loomis Talc Co., Gouverneur, N. Y. | | | |
| A | Talc-rich rock-#4 mine | St. Lawrence | New York | Do. |
| B | Commercial grade- do. | do. | do. | Do. |
| C | Large sample of 8-A-#4 mine | do. | do. | Do. |
| D | -- --#1 mine (abandoned) | do. | do. | Do. |
| E | Large sample of 8-D- do..... | do. | do. | Do. |
| F | Soft vein-#4 mine | do. | do. | Do. |
| G | #4 heading-#1 mine (abandoned) ... | do. | do. | Do. |
| H | #5 level-#4 mine | do. | do. | Do. |
| I | Levels #5 and #6-#1 mine | do. | do. | Do. |
| J | #1-C-tremoline- -- | do. | do. | Do. |
| K | #4-steatite- -- | do. | do. | Do. |
| L | Steatite-#5 mine | do. | do. | Do. |
| M | Loomis #13-Flotation concentrate-- | do. | do. | Do. |
| N | " - Test #18-#4 mine-#5 Lead. | do. | do. | Do. |
| O | " - " #32 -- -- | do. | do. | Do. |
| 9- | Castle Craig deposit, Campbell County, Va. | | | |
| A | White talc-prospect sample | Campbell | Virginia | Owner |
| B | White talc-sample #1 | do. | do. | BM |
| C | Sample #2- | do. | do. | Do. |
| D | Sample #2-deeper in quarry- | do. | do. | Do. |
| 10- | Harford Talc & Quartz Co., Bel Air, Md. | | | |
| A | New deposit-Prospect near Dublin.. | Harford | Maryland | Producer |
| B | Lava-grade talc-#1 quarry | do. | do. | Do. |
| 11- | W. O. Hoffman, Port Deposit, Md. | | | |
| A | Pencil-grade talc | Cecil | do. | Do. |

TABLE 1. - Finding list of talc samples (Numerical order) (Cont'd.)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|---------|--------------|
| | | County | State | |
| 12- | F. A. Markley, San Ysidro, Calif. | | | |
| A | White talc-Ibex Hills | Inyo | Calif. | Owner |
| B | Black talc do. | do. | do. | Do. |
| C | -- do. | do. | do. | USGS |
| D | -- do. | do. | do. | Do. |
| E | -- do. | do. | do. | Do. |
| F | -- do. | do. | do. | Do. |
| 13- | Victor Mica Co., Spruce Pine, N. C. | | | |
| A | Low-grade talc- -- | Mitchell | N. C. | Producer |
| 14- | Nantahala Talc & Limestone Co., Nantahala, N. C. | | | |
| A | Clear Talc-Hewitt mine | Swain | do. | Do. |
| B | Green talc- do. | do. | do. | Do. |
| C | White talc- do. | do. | do. | BM |
| D | Gray talc- do. (stock pile) .. | do. | do. | Do. |
| 15- | United Feldspar & Minerals Corpo- ration, Spruce Pine, N. C. | | | |
| A | Surface sample-Morris property, Winterboro | Talladega | Alabama | Do. |
| B | South of shaft- do. | do. | do. | Do. |
| C | Quarry- do. | do. | do. | Lessee |
| D | North of shaft- do. | do. | do. | BM |
| E | United #593 flotation concentrate- Morris prop.-Winterboro | do. | do. | Lessee |
| F | United #594 flotation concentrate- do. | do. | do. | Do. |
| 16- | Vermont Talc Co., Chester, Vt. | | | |
| A | Superfine XXX | Windsor | Vermont | Producer |
| 17- | Georgia Talc Co., Asheville, N. C. | | | |
| A | Cosmetic-grade talc | Mitchell | N. C. | Do. |
| 18- | James M. Hyde, Bishop, Calif. | | | |
| A | Steatite | Inyo | Calif. | Owner |
| B | White fibrous talc | do. | do. | Do. |
| 19- | Southern California Minerals Co., Los Angeles, Calif. | | | |
| A | Pigment #21 | -- | -- | Producer |
| B | Pigment #061 (see also 47-A) | -- | Calif. | Do. |
| C | Pigment #30 | -- | -- | Do. |
| D | Pigment #14 | -- | -- | Do. |
| E | Pigment #76 | -- | -- | Do. |
| F | -- Superior mine | Inyo | Calif. | USGS |
| G | Ore bin sample-Reed mine | Esmeralda | Nevada | Do. |

TABLE 1. - Finding list of talc samples (Numerical order) (Cont'd.)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|--|---------------------|----------|--------------|
| | | County | State | |
| 20- | International Pulp Co., 41 Park Row, New York, N. Y. | | | |
| A | 3X-Asbestine | St. Lawrence | New York | Producer |
| B | 5X-Asbestine | do. | do. | Do. |
| C | White foliated talc | do. | do. | Do. |
| D | Large sample of C | do. | do. | Do. |
| E | Ceramitalc | do. | do. | Do. |
| F | -- | -- | -- | Brokers |
| G | -- | St. Lawrence | New York | Do. |
| 21- | Clinchfield Sand & Feldspar Corporation, 430 Hearst Tower Bldg., Baltimore, Md. (H. N. Hanna, Pres.) | | | |
| A | 300 M talc-Marriottsville | Howard | Maryland | Producer |
| B | 300 H talc- do. | do. | do. | Do. |
| C | D L talc -- | -- | -- | -- |
| D | X talc (see 51-series)-Lansing property | St. Lawrence | New York | Broker |
| E | Hillside talc do. do. | do. | do. | Do. |
| F | Moneta -- | -- | Virginia | Do. |
| G | B L #10 -- | -- | -- | Do. |
| 22- | Stupakoff Ceramic & Mfg. Co., Latrobe, Pa. | | | |
| A | #1 talc (used in manufacturing).... | -- | -- | Mfr. |
| B | #2 talc (preferred in manufacturing) | -- | -- | Do. |
| 23- | Ernest Huhn & Louisa Grantham | | | |
| A | Bottom of vein-#5 claim Warm Spring Canyon, Panamint Range | Inyo | Calif. | USGS |
| B | Middle of vein do. | do. | do. | Do. |
| C | Top of vein do. | do. | do. | Do. |
| D | Above drift, nearest fork- do. | do. | do. | Do. |
| 24- | Phil Thomas, Ibex Hills | | | |
| | #10 from ore bin-Superior mine-Saratoga Springs | do. | do. | Do. |
| 25- | Justin Gates | | | |
| A | -- Hideout claims.. | Esmeralda | Nevada | Do. |
| B | Blue talc -- | do. | do. | Do. |
| C | Ore-bine sample-Cowhide claim | do. | do. | Do. |

TABLE 1. - Finding list of talc samples (Numerical order (Cont'd.))

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|---------|--------------|
| | | County | State | |
| 26- | Ganim Gold mine | | | |
| A | Green steatite | Shasta | Calif. | BM-Econ.Br. |
| B | Surface | do. | do. | Broker |
| C | #1 Raise from chute | do. | do. | Do. |
| D | Near hanging wall | do. | do. | Do. |
| E | From hanging wall | do. | do. | Do. |
| F | Middle of dike | do. | do. | Do. |
| G | Near middle of dike | do. | do. | Do. |
| H | 100 ft. from raise north-center of dike | do. | do. | Do. |
| I | Massive greenish talc | do. | do. | Owner |
| J | Green talc | do. | do. | BM engrs. |
| K | Light-green talc | do. | do. | Do. |
| L | Crosscut | do. | do. | USGS |
| M | 6 ft. exposure | do. | do. | Do. |
| 27- | Eastern Magnesia Talc Co., Burlington, Vt. | | | |
| A | Commercial-grade talc #500 | Lamoille | Vermont | Producer |
| 28- | Wm. Rossman Tri-Angle Co., Box 878, Pecos, Tex. | | | |
| A | West Texas | | | Owner |
| 29- | U. S. Diatom Co., 800 Santa Fe Ave., Los Angeles, Calif. | | | |
| A | Run-of-mine talc-Death Valley Property | Inyo | Calif. | USGS |
| 30- | Globe-Union, Inc., 900 E. Keefe Ave., Milwaukee, Wis. | | | |
| A | Talc used in manufacturing | -- | -- | Mfr. |
| 31- | Western Talc Co., 1901 E. Slauson Ave., Los Angeles, Calif. | | | |
| A | Soft talc-Western Talc mine | San Bernardino | Calif. | USGS |
| B | "M" talc | do. | do. | Producer |
| 32- | Harris Limestone Co., Lonsdale, R.I. | | | |
| A | -- | Cumberland | R. I. | Do. |
| 33- | Roy Bradley, Big Pine, Calif. | | | |
| A | Doris Dee #2 claim | Inyo | Calif. | USGS |
| B | do. #3 do. | do. | do. | Do. |
| C | do. #3 do. | do. | do. | Do. |

TABLE 1. - Finding list of talc samples (Numerical order (Cont'd.))

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|---------|--------------|
| | | County | State | |
| 34- | Commercial Minerals Co., 310 Irwin St., San Francisco, Calif. | | | |
| A | Run-of-mine talc-Ganym Gold Mine (See 26 series) | Shasta | Calif. | Brokers |
| B | do | do. | do. | Do. |
| 35- | Watson Ritch, Engle, N. Mex. | | | |
| A | From cut in canyon-Hembrillo mine, Hembrillo Canyon, San Andres Range | Dona Ana | N. Mex. | USGS |
| 36- | Watson Ritch, Engle, N. Mex. | | | |
| A | Stock sample-Red Rock Mine near Hembrillo Canyon, San Andres Range | do. | do. | Do. |
| 37- | Philip S. Hoyt, Box 347, Van Horn, Tex. | | | |
| A | Massive green talc -- | -- | Wyoming | Prospector |
| 38- | Ben R. Binns, 2974 Glenmore Place, Los Angeles, Calif. | | | |
| A | White talc-Pleasanton mine | San Bernardino | Calif. | Owners |
| B | White talc (large sample of 38-A)-Pleasanton mine | do. | do. | Do. |
| C | From ore pile do. | do. | do. | USGS |
| D | do. do. | do. | do. | Do. |
| E | #28 (from H. N. Hanna-see 21 series) do. | do. | do. | Broker |
| F | #29 do. do. | do. | do. | Do. |
| 39- | Tri-State Minerals Co., 2005 Lincoln Ave., Ogden, Utah (Subsidiary or agents for So. Cal. Minerals Co.-see 19 series) | | | |
| A | Dillon ceramic talc-Smith-Dillon mine | Beaverhead | Montana | Producer |
| B | Mica talc do. | do. | do. | Do. |
| C | do. do. | do. | do. | Do. |
| 40- | Mineral Mining Corporation, Kershaw, S. C. | | | |
| A | Sericite | -- | S. C. | Do. |
| 41- | Mariposa Talc Co., 1516 N. La Brea, Los Angeles, Calif. | | | |
| A | Adit-Mariposa talc mine | Mariposa | Calif. | USGS |
| B | Cut- do. | do. | do. | Do. |

TABLE 1. - Finding list of talc samples (Numerical order)(Cont'd.)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|---------|--------------|
| | | County | State | |
| 42- | Louis S. McCollum, 1310 Rhodes-Haverty Bldg., Atlanta, Ga. | | | |
| A | -- | -- | Calif.? | Broker |
| B | Beneficiated sample | -- | do. | Do. |
| 43- | Phillips Bros., 70 Pine St., New York, N. Y. | | | |
| A | (see also #60-A) W-90-S-Rosamelia mine | Esmeralda | Nevada | Do. |
| B | W-12-M-(same as A but different sizing)-Rosamelia mine | do. | do. | Owners |
| C | W-90-S- do. | do. | do. | Broker |
| 44- | Charles A. Wagner Co., 813-15 Callowhill St., Philadelphia, Pa. | | | |
| A | #124-Sundown mine-Blue Star mines. | Esmeralda | Nevada | Broker |
| B | Superfine do. | do. | do. | Do. |
| C | Cawramic 1240- do. | do. | do. | Do. |
| D | Superfine Cawramic- do. | do. | do. | Do. |
| 45- | Halsey B. Leavitt, 28 Bank of Asheville Bldg., Asheville, N. C. | | | |
| A | Tully talc | Mitchell? | N. C.? | Producer |
| 46- | Alliance mine, Lockhart & Koest, Darwin, Calif. | | | |
| A | 85-ft. level (see also 1-N)-Alliance mine, near Keeler | Inyo | Calif. | USGS |
| B | Irish lease do. | do. | do. | Do. |
| C | Dark talc do. | do. | do. | Do. |
| 47- | Whittaker, Clark & Daniels, 260 W. Broadway, New York City | | | |
| A | #061 talc -- | ? | do. | Broker |
| B | French talc -- | -- | -- | Do. |
| C | Indian talc #455 -- | -- | -- | Do. |
| D | Calcined talc "061" -- | -- | -- | Do. |
| 48- | Muroc Clay Co., 5509 Randolph St., Los Angeles, Calif. | | | |
| A | Muroc #1-)Purchases talc from | (Inyo | Calif. | Producer |
| B | Muroc #2-)various sources in- | (or | or | Do. |
| C | Muroc #3-)cluding Nos. 46 and 64.. | Esmeralda | Nevada | Do. |
| 49- | J. S. Madigan, 86 W. Colorado St., Pasadena, Calif. | | | |
| A | P-1 talc-mine near Keeler | Inyo | Calif. | -- |

TABLE 1. - Finding list of talc samples (Numerical order) (Cont'd.)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|----------|--------------|
| | | County | State | |
| 50- | O. Hommel Co., 209 Fourth Ave., Pittsburgh, Pa. | | | |
| A | Synthetic talc, OHCO #7662 -- | -- | -- | Brokers |
| 51- | Northern New York Mining Corporation, Gouverneur, N. Y. | | | |
| | C. H. Sprague, Richville, N. Y. | | | |
| A | Hillside talc-Lansing property, near Edwards | St. Lawrence | New York | Producer |
| B | X-talc do... | do. | do. | Do. |
| C | X-talc N. side of pit do... | do. | do. | BM engrs. |
| D | X-talc do. do... | do. | do. | Do. |
| E | X-talc S. side of pit do... | do. | do. | Do. |
| F | Hillside talc-N. side of pit do... | do. | do. | Do. |
| 52- | Clark-Teutsch mines, Johnny Gulch, Mont. | | | |
| A | West lenses | Madison | Montana | USGS |
| B | do. | do. | do. | Do. |
| C | East lenses | do. | do. | Do. |
| D | do. | do. | do. | Do. |
| E | West lenses | do. | do. | Do. |
| F | East lenses, lava grade | do. | do. | Do. |
| G | do. | do. | do. | Do. |
| H | New adit on north hill | do. | do. | Do. |
| 53- | J. S. Hartzell, 1326 Fidelity- Philadelphia Trust Bldg., Phila.Pa. | | | |
| A | -- near Marion | McDowell | N. C. | Producers |
| 54- | L. A. Salomon & Bros., 216 Pearl St., New York City | | | |
| A | Talc #48-See No. 48 or No. 64 series-Paramount claims ? | Esmeralda? | Nevada? | Broker |
| B | Talc #60 | -- | N. Mex. | Do. |
| 55- | Imperial Talc Co., Allied Products Co., Suffern, N. Y. | | | |
| A | Special B talc | | | Mfr. |
| 56- | Charles Mathiew Talc Co., Allied Products Co., Suffern, N. Y. | | | |
| A | Italian talc-cosmetic grade | | | Do. |
| 57- | Overseas Trading Co., 420 Lexington Ave., New York, N. Y. | | | |
| A | Canadian talc | | | Importer |

TABLE 1. - Finding list of talc samples (Numerical order) (Cont'd.)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|--------|--------------|
| | | County | State | |
| 58- | Pratt, Lassiter, & Watkins, Capital Club Bldg., Raleigh, N. C. | | | |
| A | -- | Wake | N. C. | Producer |
| 59- | Blue Star Mines, Inc., 610 S. Spring St., Los Angeles, Calif. | | | |
| A | White talc-sorted from bin-Sundown mine-Palmetto (Oasis) dist. | Esmeralda | Nevada | USGS |
| B | Blue talc- do. | do. | do. | Do. |
| 60- | Nevada Minerals Co., Los Angeles, Calif. | | | |
| A | 1-inch Mill product, minus fines-see No. 43-Poseamelia mine..... | do. | do. | Do. |
| B | "Blue talc from ore bin do. | do. | do. | Do. |
| 61- | M. D. and W. E. MacBoyle, and J. E. King, Oasis, Calif. | | | |
| A | Run-of-mine talc-White King mine, Palmetto (Oasis) dist. | do. | do. | Do. |
| B | Select talc do. do. | do. | do. | Do. |
| C | do. -Crystal White claim do. | do. | do. | Do. |
| D | "MacBoyle's blue talc"-from ore bin-White King No. 1 claim-Palmetto (Oasis) district | do. | do. | Do. |
| 62- | Laurel M. and Gertrude Dust, (Oasis, Calif.?) | | | |
| A | Composite sample-White Eagle #1 and #2 claimsdo. | do. | do. | Do. |
| B | Run-of-mine -White Eagle mine-do. | do. | do. | Do. |
| 63- | Roscoe (Curly) Wright, Oasis, Calif. | | | |
| A | Curly's talc (select)-Curly mine do. | do. | do. | Do. |
| 64- | Gus Krause, Oasis, Calif. | | | |
| A | Selected sample from stope-Paramount mine do..... | do. | do. | Do. |
| 65- | Joe Andre and Tex Rogers, Oasis, Calif. | | | |
| A | Dark-grey talc from stope-Lone Spring mine- | do. | do. | Do. |
| B | Light talc from stope- do. | do. | do. | Do. |
| 66- | Oliver and Harvey, Oasis, Calif. | | | |
| A | From ore pile-Belle claim | do. | do. | Do. |
| 67- | Sam Hain, Oasis, Calif. | | | |
| A | Run-of-mine-Oversight claim-Palmetto (Oasis) district | Esmeralda | Nevada | USGS |

TABLE 1. - Finding list of talc samples (Numerical order) (Cont'd.)

| Sample No. | Sample identification | Location of deposit | | Sampled by - |
|------------|---|---------------------|-----------|--------------|
| | | County | State | |
| 68- | G. P. Rodgers & Frank Henderson, Big Pine, Calif. | | | |
| A | White-Eleanor claim-near Big Pine. | Inyo | Calif. | USGS |
| B | Dark- do. do. ... | do. | do. | Do. |
| 69- | Walter Sorenson, Lone Pine, Calif. | | | |
| A | Run-of-mine talc-Blue Stone mine-East of Independence | do. | do. | Do. |
| 70- | Sam Lenbek & E. Bergland, Lone Pine, Calif. | | | |
| A | -- White Star claim-N. of Keeler | do. | do. | Do. |
| 71- | Canadian Bureau of Mines, Ottawa, Ontario, Canada | | | |
| A | Beneficiated talc-Madoc, Ottawa, Ont., Canada | | | Can. BM |
| 72- | Newton Talc Property, J. J. Wallace, Talcville, N. Y. | | | |
| A | Hole #2-99' to 149' Newton property, near Talcville | St. Lawrence | New York | BM |
| B | Hole #2-149' to 180.5' do..... | do. | do. | Do. |
| C | Hole #2-180.5' to 198' do..... | do. | do. | Do. |
| D | Hole #3-281' to 301' do..... | do. | do. | Do. |
| E | Hole #3-301' to 320' do..... | do. | do. | Do. |
| 73- | Roy S. Leonard, 2409 Cameron Mills Rd., Alexandria, Va. | | | |
| A | Lava (?) talc | ? | Virginia? | ? |
| 74- | W. O. Davis deposit, Gillespie County, Tex. | | | |
| A | #1 | Gillespie | Texas | BM |
| B | #2 | do. | do. | Do. |
| C | #3 | do. | do. | Do. |
| 75- | Heyman Co., 157 Chambers St., New York, N. Y. | | | |
| A | Jaipur talc | | India | Broker |
| 76- | Hamilton Associates, 646 N. Michigan Ave., Chicago, Ill. | | | |
| A | Northern California product | -- | Calif. | No data |
| B | Southern sample #1 | -- | do. | Do. |
| C | Regular Southern California | -- | do. | Do. |
| D | Select Southern California | -- | do. | Do. |
| 77- | W. H. Huntley | | | |
| A | White Eagle Mine, Inyo Range, overlooking Saline Valley | Inyo | do. | Producer |
| B | do. | do. | do. | Do. |

TABLE 2. - Results of tests on raw materials

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|--|--------------------------------|------|--------------------------|-----------------------|------------------------------------|---------------|------------------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 1- A-1/ | 1.26 | 0.62 | | Cream | 1-2 carbonates | Standard | S ₂ / |
| B | 1.21 | .42 | | do. | Trace-1 carbonates | | S |
| C | 1.23 | .08 | | do. | 2-5 carbonates, quartz, fluorspar | | S |
| D | 1.24 | .57 | | do. | 5-10 carbonates, tremolite | | S |
| E | 1.34 | .09 | | do. | 1 carbonates | | S |
| (A to E all used by manufacturers. Taken as standards for comparison. See end of table for complete analyses). | | | | | | | |
| F | 1.11 | 9.16 | | Fused | 50 carbonates | | U ₂ / |
| F-c ₄ / | .77 | 3.72 | 37 | Cream | 3-5 carbonates | | U |
| G | 1.24 | 4.64 | | Lt. brown | 50 carbonates | | U |
| G-c | .83 | 1.30 | 37 | Cream | 3-5 carbonates | | S |
| H | 1.43 | 1.34 | | Buff | 20 carbonates | | U |
| H-c | .90 | .63 | 40 | Cream | 1 carbonate | | S |
| I | 1.18 | 6.60 | | Brown | 35 carbonates | | U |
| I-c | 1.33 | 1.06 | 44 | Cream | 1 carbonates | | S |
| J | .34 | 3.64 | | do. | 20 carbonates | | U |
| J-c | .31 | .73 | 36 | White | 2 carbonates | | S |
| K | 1.68 | .73 | | Cream | 3 carbonates | | U |
| K-c | 1.42 | .25 | 54 | do. | Trace carbonates | | S |
| L | 1.30 | 1.82 | | Mottled | 10 carbonates | | U |
| L-c | 1.19 | .76 | 35 | Cream | 2 carbonates | | S |
| M | 1.45 | 1.70 | | Gray | 25 carbonates, tremolite, chlorite | | U |
| M-c | 1.21 | .02 | 33 | Cream | Trace carbonates | | S |
| N | .80 | .02 | | Lt. cream | 2 carbonates | Very soft | S |
| N-c | .76 | .02 | 81 | do. | Trace carbonates | | S |
| O | 1.00 | 1.23 | | do. | 2-5 carbonates | | S |
| O-c | .92 | .15 | 64 | do. | Trace carbonates | | S |

1/ Samples are "as received" unless otherwise designated.

2/ S designates satisfactory substitutes for Sierra talc.

3/ U designates unsatisfactory substitutes for Sierra talc.

4/ Samples designated "c" are flotation concentrates.

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--|-------|--------------------------|-----------------------|-----------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 1- P | 1.31 | 1.16 | | Lt. cream | 2-5 carbonates | | S |
| P-c | 1.17 | .14 | 79 | do. | Trace carbonates | | S |
| R | .86 | 3.44 | | Buff | 5-10 carbonates | | U |
| R-c | .31 | .42 | 61 | Cream | 1 carbonates | | S |
| S | 1.06 | .88 | | Buff | 3 carbonates | | S |
| S-c | 1.00 | .15 | 86 | Ivory | 1 carbonates | | S |
| T | .58 | .07 | | Buff | 1 carbonates | | S |
| T-c | .54 | .16 | 80 | Ivory | Trace carbonates | | S |
| U | 1.50 | .09 | | Cream | 75-90 serpentine | Soft | U |
| 2- A | 6.82 | 1.72 | | Black | 10-15 carbonates, magnetite | | U |
| A-c | 4.95 | .58 | 53 | Brown | 5-carbonates, magnetite | | U |
| B | 8.68 | .29 | | Tan | 5-10 magnetite, chlorite | | U |
| B-c | 1.86 | .06 | 44 | do. | Trace magnetite, chlorite | | U |
| C | MgCO ₃ -7.45 percent No further tests | | | | 50-75 carbonates, magnetite | | U |
| 3- A | 6.05 | 3.21 | | Brown | 70 tremolite, carbonates | | U |
| A-c | 5.35 | 1.43 | 64 | do. | 50 tremolite, carbonates | | U |
| 4- A | .54 | 19.94 | | Lt. cream | 50-75 carbonates | Soft | U |
| A-c | .52 | 20.35 | 61 | White | 50 carbonates | | U |
| B | 1.16 | 5.62 | | do. | 75 tremolite, mica, etc. | | U |
| B-c | Would not float under standard conditions | | | | | | |
| 5- A | 11.8 | .35 | | Brown | 75 chlorite | | U |
| A-c | 7.24 | .02 | 3 | Lt. brown | 10-15 chlorite | | U |
| 6- A | 2.20 | .09 | | Cream | 1 rutile, zircon | | U |
| A-c | 1.29 | .04 | 35 | do. | Trace rutile, zircon | | S |
| B | 2.11 | .04 | | Gray | 1 rutile, zircon | Very soft | U |
| B-c | 1.61 | .08 | 37 | Lt. gray | Trace rutile, zircon | | S |
| C | 1.83 | .05 | | Gray | 1 iron-stained flakes | | U |
| C-c | 1.47 | .02 | 49 | Lt. gray | Trace iron-stained flakes | | S |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|-----------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 7- A | 6.05 | 0.31 | | Tan | 70 carbonates | | U |
| A-c | 2.90 | .02 | 43 | Gold | 1 carbonates | | U |
| 8- A | .58 | 1.95 | | White | 65 tremolite | | U |
| A-c | .43 | .05 | 53 | do. | 10-15 tremolite | | S |
| B | .29 | 6.43 | | do. | 90 tremolite, carbonates | | U |
| B-c | .29 | 3.77 | 10 | do. | | | U |
| C | .19 | 6.38 | | do. | 50-75 tremolite, carbonates | | U |
| C-c | .14 | .44 | 32 | do. | 35 tremolite, carbonates | | S |
| D | .03 | 3.18 | | do. | 50 tremolite, carbonates | | U |
| D-c | .03 | .36 | 47 | do. | 3 tremolite, carbonates | | S |
| E | .12 | 2.68 | | do. | 50 tremolite, carbonates | | U |
| E-c | .11 | .10 | 46 | do. | 1 tremolite, carbonates | | S |
| F | .13 | .76 | | do. | 50 tremolite, quartz | | S |
| F-c | .10 | .10 | 55 | do. | Trace tremolite, quartz | | S |
| G | .14 | 2.86 | | do. | 75- tremolite, quartz | | U |
| G-c | .12 | .05 | 44 | do. | 1- tremolite, quartz | | S |
| H | .39 | 1.97 | | do. | 50-75 tremolite, quartz | Very hard | U |
| H-c | .41 | .86 | 60 | do. | 40 tremolite | | S |
| I | Not tested; by request | | | | | | |
| J | .36 | 6.02 | | do. | 50 tremolite | Very hard | U |
| J-c | .07 | 3.66 | 50 | do. | 50 tremolite | | U |
| K | .20 | 1.03 | | do. | 3-5 tremolite, amphibole | Very hard | S |
| K-c | .19 | .90 | | do. | 3-5 tremolite, amphibole | | S |
| L | .35 | 1.31 | | do. | 50-75 tremolite, quartz | Hard | Blend |
| M | .33 | .35 | | do. | 5 tremolite, quartz | Std. | S |
| N | .38 | .74 | | do. | 5 tremolite, quartz | do. | S |
| O | .21 | .22 | | do. | | do. | S |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|-----------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 9- A | 1.94 | 0.10 | | Lt. buff | Trace feldspar and biotite | | U |
| A-c | 1.74 | .05 | 79 | do. | do. | | U |
| B | 1.64 | .80 | | Cream | 1-2 tremolite | | U |
| B-c | 1.45 | .07 | 58 | do. | Trace tremolite | | S |
| C | 1.86 | .78 | | do. | 15 tremolite | Std. | Blend |
| C-c | 1.36 | .06 | 60 | Ivory | 2-3 tremolite | | S |
| D | 1.96 | .50 | | Buff | 3-5 tremolite, limonite | | Blend |
| D-c | 2.25 | .07 | 65 | Cream | 1-2 tremolite, limonite | | Do. |
| 10- A | 4.63 | .10 | | Red-brown | 30 tremolite | | U |
| A-c | 4.46 | .16 | 63 | Lt. brown | 1 tremolite | | U |
| B | 8.96 | .06 | | Brown | 5 magnetite, iron stain | | U |
| B-c | 7.86 | .04 | 60 | do. | 1 magnetite, iron stain | | U |
| 11- A | 10.3 | .08 | | Red-tan | 50-75 chlorite | | U |
| A-c | 6.80 | .10 | 43 | Brown | 5 chlorite, magnetite | | U |
| 12- A | 1.37 | .61 | | White | 10 carbonates | | S |
| A-c | 1.47 | .58 | 45 | do. | 2 carbonates | | S |
| B | Not tested | | | | | | U |
| C | .34 | 1.66 | | do. | 15 carbonates | | S |
| C-c | .16 | 1.24 | 17 | do. | 3 carbonates | | S |
| D | .37 | 2.20 | | Lt. cream | 3 carbonates | | U |
| D-c | .18 | 2.28 | 19 | White | 1-2 carbonates | | U |
| E | .36 | 2.48 | | Cream | 5-10 carbonates | | U |
| E-c | .18 | 1.96 | 21 | White | 3 carbonates | | Blend |
| F | .29 | 5.25 | | Cream | 10 carbonates, chalcedony | | U |
| F-c | .23 | 5.75 | 22 | do. | 10 carbonates, chalcedony | | U |
| 13- A | 6.92 | .01 | | Dk. brown | 90 micaceous | | U |
| A-c | 4.73 | .03 | 32 | Lt. brown | 90 micaceous | | U |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|-----------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 14- A | 1.64 | 0.05 | | Lt. buff | Trace apatite | | S |
| B | 7.50 | .01 | | Tan. | 95 serpentine | | U |
| C | 1.36 | .25 | | Gray | 1-2 carbonates | | S |
| C-c | 1.14 | .00 | 47 | White | Trace carbonates | | S |
| D | 8.40 | .10 | | Brown | 100 green chlorite | Very soft | U |
| 15- A | .93 | .06 | | Cream | 15 iron stain, limonite | | S |
| A-c | .68 | .06 | 76 | White. | 1-2 iron stain, limonite | | S |
| B | 1.88 | .11 | | do. | 10 iron stain, limonite | | Blend |
| B-c | .92 | .20 | 65 | do. | 2-3 iron stain, limonite | | S |
| C | 3.65 | .02 | | Red buff | 30 opaques, iron stain | | U |
| C-c | .79 | .03 | 53 | Cream | 1 opaques, iron stain | | S |
| D | 1.20 | .06 | | Cream | 2 opaques, iron stain | | S |
| D-c | .70 | .07 | 79 | Lt. cream | 1 opaques, iron stain | | S |
| E | 1.21 | .08 | | do. | 3-5 limonite | | S |
| F | .65 | .05 | | Ivory | Trace limonite | | S |
| 16- A | 6.16 | .64 | | Brown | 50 carbonates, magnetite | | U |
| A-c | 3.40 | .06 | 25 | Buff | 2-3 carbonates, magnetite | | U |
| 17- A | 5.03 | 2.58 | | Dk. brown | 50 carbonates, magnetite | | U |
| A-c | 3.07 | .04 | 25 | Dk. buff | 2-3 carbonates | | U |
| 18- A | .57 | 4.61 | | Cream | 50 carbonates | | U |
| A-c | .65 | .05 | 40 | White | Trace carbonates | | S |
| B | .31 | 2.58 | | do. | 30 carbonates, tremolite | | U |
| B-c | .33 | .12 | 45 | do. | Trace carbonates, tremolite | | S |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|-----------------------------------|------------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 19- A | 1.16 | 2.68 | | Cream | 20 carbonates, tremolite | | U |
| A-c | 1.20 | .22 | 39 | do. | Trace carbonates, tremolite | | S |
| B | .29 | 6.64 | | White | 80 carbonates, tremolite | | U |
| B-c | .29 | 2.38 | 19 | do. | 60 carbonates, tremolite | | U |
| C | 1.00 | 4.62 | | Cream | 5-10 carbonates, tremolite | | U |
| C-c | 1.00 | .24 | 41 | do. | 1 carbonates, tremolite | | S |
| D | .34 | .16 | | White | 1 carbonates | | S |
| D-c | .14 | .06 | 76 | Cream | Trace carbonates | | S |
| E | 1.33 | 3.76 | | Buff | 15 carbonates, tremolite | | U |
| E-c | 1.43 | .40 | 50 | do. | 5-carbonates, tremolite | | S |
| F | .32 | 3.46 | | White | 50 tremolite | | U |
| F-c | .32 | 1.47 | 19 | do. | 15 tremolite | | S |
| G | 1.26 | .14 | | Cream | 5 chlorite, carbonates | | S |
| 20- A | .12 | 5.84 | | White | 50-75 tremolite, carbonates | | U |
| A-c | .14 | 3.25 | 7 | do. | 40 tremolite, carbonates | | U |
| B | .14 | 3.44 | | do. | 50-75 tremolite | | U |
| B-c | .34 | 3.14 | 20 | do. | 25 tremolite | | U |
| C | .03 | .93 | | do. | 15-20 tremolite | | S |
| C-c | .13 | .06 | 72 | do. | 1 tremolite | | S |
| D | .29 | .73 | | do. | 50-75 tremolite, quartz | | S |
| D-c | .20 | .15 | 27 | do. | Trace tremolite, quartz | | S |
| E | .16 | 7.95 | | do. | 100 tremolite | | U |
| F | .54 | 2.05 | | do. | | No further tests | U |
| G | .46 | 1.77 | | do. | 50 tremolite | do. | U |
| 21- A | 9.95 | .93 | | Dk. brown | 90 tremolite, magnetite, chlorite | | U |
| A-c | 5.11 | .03 | 39 | Fused | 35 tremolite, magnetite, chlorite | | U |
| B | 9.45 | .36 | | Dk. brown | 90 tremolite, magnetite, chlorite | | U |
| B-c | 4.98 | .04 | 39 | Fused | 35 tremolite, magnetite, chlorite | | U |
| C | 2.09 | .12 | | Buff | 3-5 tremolite, carbonates | | U |
| C-c | 2.03 | .11 | 54 | Dk. buff | Trace tremolite, carbonates | | U |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|------------------------------------|---------------|---------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 21- D | 0.37 | 3.02 | | White | 5 tremolite, carbonates | | U |
| D-c | .31 | 1.54 | 74 | do. | 1 tremolite, carbonates | | S |
| E | .57 | .11 | | Cream | 5-10 carbonates, quartz, tremolite | | S |
| E-c | .59 | .06 | 53 | White | 2 carbonates, quartz, tremolite | | S |
| F | 1.13 | 1.37 | | Ivory | 35 tremolite | | S |
| G | 5.84 | .08 | | -- | No further tests | | U |
| 22- A | 1.07 | 4.33 | | Cream | 15 carbonates | Soft Std. | Blend S |
| B | .74 | 1.77 | | White | 5-10 carbonates | | |
| 23- A | .36 | 6.65 | | do. | 15 carbonates, tremolite | | U |
| A-c | .16 | 2.26 | 24 | do. | 5-10 carbonates, tremolite | | U |
| B | .36 | 5.55 | | do. | 35 tremolite, carbonates | | U |
| B-c | .24 | 2.55 | 32 | do. | 20 tremolite, carbonates | | U |
| C | .23 | 6.30 | | do. | 35 tremolite, carbonates | | U |
| C-c | .16 | 2.52 | 37 | do. | 20 tremolite, carbonates | | U |
| D | .07 | 6.10 | | do. | 35 tremolite, carbonates | | U |
| D-c | .17 | 2.20 | 30 | do. | 20 tremolite, carbonates | | U |
| 24- A | .31 | 5.19 | | do. | 65 tremolite, carbonates | | U |
| A-c | .34 | 2.36 | 25 | do. | 50 tremolite, carbonates | | U |
| 25- A | 1.46 | .19 | | Green | 70-90 antigorite | | U |
| B | 1.61 | .07 | | Ivory | 35 chlorite | | U |
| B-c | 1.12 | .09 | 15 | White | 3-5 chlorite | | S |
| C | .87 | .12 | | Off-white | Trace specks | | S |
| 26- A | 1.17 | 3.19 | | Yellowish | 20 carbonates, tremolite | | U |
| A-c | 1.01 | 1.08 | 40 | Cream | 3 carbonates, tremolite | | S |
| B | 1.06 | .04 | | Lt. cream | 3-5 tremolite | | S |
| B-c | .96 | .01 | | do. | Trace tremolite | | S |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|-------|--------------------------|-----------------------|---------------------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 26- C | 0.81 | 1.30 | | Lt. cream | 3-5 tremolite | | S |
| C-c | .82 | .02 | 48 | White | 1 tremolite | | S |
| D | .79 | 26.89 | | Fused | 50-75 carbonates | | U |
| D-c | .75 | 12.46 | | do. | 15-20 carbonates | | U |
| E | 1.04 | .31 | | Cream | 2 carbonates, tremolite, etc. | | S |
| E-c | 1.00 | .03 | 46 | White | Trace carbonates, tremolite, etc. | | S |
| F | 1.18 | .01 | | Mottled | 2 carbonates, tremolite | | S |
| F-c | 1.25 | .02 | 45 | White | Trace carbonates, tremolite | | S |
| G | .79 | .71 | | Mottled | 3 carbonates, tremolite | | S |
| G-c | .65 | .22 | | White | Trace carbonates, tremolite | | S |
| H | 1.07 | .06 | | Buff | Trace carbonates, chlorite | | S |
| H-c | 1.07 | .02 | 48 | White | Trace carbonates, chlorite | | S |
| I | 1.00 | 1.19 | | Cream | 2-5 carbonates | | S |
| I-c | .97 | .83 | 43 | Lt. cream | 1 carbonates | | S |
| J | 1.32 | 2.94 | | do. | 20 carbonates | | S |
| J-c | 1.24 | 1.00 | 51 | do. | 5 carbonates | | U |
| K | .39 | 31.10 | | No test | 80-90 carbonates | | S |
| K-c | .56 | 18.15 | 36 | No test | 70-80 carbonates | | U |
| L | 2.93 | 12.65 | | Cream | 50-75 sulfides, carbonates, quartz | | U |
| L-c | 1.23 | 4.66 | 51 | do. | 5-10 sulfides, carbonates, quartz | | U |
| M | 1.14 | 3.13 | | do. | 5-10 carbonates | | U |
| M-c | 1.16 | .88 | 54 | do. | 2-3 carbonates | Soft | S |
| 27- A | 3.06 | .61 | | Dk. brown | 5-10 carbonates | | U |
| A-c | 3.89 | .32 | 78 | do. | 3 carbonates | | U |
| 28- A | .08 | 5.32 | | White | 25 carbonates, biotite, orthochlorite | | U |
| A-c | .06 | 1.40 | 26 | do. | 35 carbonates, biotite | | S |
| 29- A | 1.45 | 5.95 | | White | 10 carbonates, tremolite | | U |
| A-c | .29 | 2.56 | 16 | do. | 2 carbonates, tremolite | | U |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|-------|--------------------------|-----------------------|--------------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 30- A | 1.15 | 0.05 | | Cream | 3 carbonates, chlorite, quartz | Std. | S |
| 31- A | .39 | 4.75 | | Lt. gray | 50 carbonates | | U |
| A-c | .36 | 5.17 | 13 | White | 10 carbonates | | U |
| B | .57 | 9.67 | | Lt. gray | 50 carbonates, tremolite | | U |
| B-c | .37 | 6.44 | 25 | White | 5 carbonates, tremolite | | U |
| 32- A | .40 | 15.80 | | Brown | 50-75 carbonates | | U |
| A-c | .41 | 4.44 | 29 | Lt. cream | 35-50 carbonates | | U |
| 33- A | 2.31 | .28 | | Brown | Small iron, trace carbonate | | U |
| A-c | 1.52 | .18 | 37 | do. | Trace iron and carbonate | | S |
| B | 2.31 | .58 | | Tan | 2 carbonates, chlorite | | Blend |
| C | 2.58 | .03 | | Lt. brown | 1-2 tremolite, carbonates | | Do. |
| 34- A | 1.05 | 2.02 | | Lt. cream | 3 carbonates | | Do. |
| B | .97 | 1.89 | | Cream | 5 carbonates | | Do. |
| B-c | .96 | .42 | 60 | Lt. cream | 1 carbonates | | S |
| 35- A | 1.72 | .10 | | Lt. gray | 3 limonite, rutile | Very soft | S |
| A-c | 1.42 | .00 | 45 | Lt. cream | 2 limonite, rutile | | S |
| 36- A | .56 | .03 | | Lt. cream | 1 carbonates and limonite | Soft | S |
| A-c | .56 | .01 | 50 | Cream | Trace carbonates and limonite | | S |
| 37- A | .79 | .23 | | No test | 100 chlorite | | U |
| 38- A | .29 | 4.35 | | White | 20 tremolite, carbonates | | U |
| A-c | .30 | 3.80 | 12 | do. | 5-10 tremolite, carbonates | | U |
| B | .32 | 5.75 | | do. | 50 carbonates, tremolite | | U |
| B-c | .35 | 2.80 | 25 | do. | 30 carbonates, tremolite | | U |
| C&D | .36 | 5.48 | | do. | 30-50 carbonates, tremolite | Soft | U |
| C&D-c | .50 | 2.78 | 29 | do. | 25 carbonates, tremolite | | U |
| E | .37 | 5.20 | | do. | 50-75 carbonates, tremolite | | U |
| F | .41 | 5.75 | | do. | 50-75 carbonates, tremolite | | U |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|------------------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 39- A | 1.32 | 0.55 | 68 | White | Traces only | Soft | S |
| A-c | 1.24 | .06 | | do. | do. | | S |
| B | 1.37 | 1.10 | | do. | 5-10 carbonates, tremolite, quartz | | S |
| C | 1.42 | 1.11 | | Cream | 5-10 carbonates, tremolite | | S |
| C-c | 1.27 | .17 | | Lt. cream | 3-5 carbonates, tremolite | | S |
| 40- A | .59 | .61 | 58 | No test | | Very soft | U |
| A | 2.65 | 2.83 | | Tan | 5-10 carbonates | | U |
| A-c | 2.74 | .44 | | do. | 1 carbonates | | U |
| B | 5.12 | .42 | | Brown | 5-10 carbonates | | U |
| B-c | 4.57 | .08 | | do. | 1 carbonates | | U |
| 42- A | .37 | 15.1 | 44 | White | 50-75 carbonates | | U |
| A-c | .55 | 8.52 | | do. | 25-35 carbonates | | U |
| B | .36 | .25 | | do. | Trace carbonates | | S |
| A | 1.14 | .79 | | White | 3-5 carbonates and tremolite | | S |
| B | 1.11 | 1.61 | | Buff | 5-10 carbonates, tremolite | | Blend |
| B-c | 1.14 | 1.30 | 66 | Cream | 5 carbonates, tremolite | Soft | S |
| C | 1.01 | .06 | | Off-white | 2-3 carbonates, tremolite | | S |
| A | .77 | .73 | | White | 1-2 carbonates | | S |
| B | 2.00 | 1.17 | | Cream | 3-5 carbonates | | Blend |
| B-c | 1.06 | .30 | | Ivory | Trace carbonates | | S |
| C | .47 | .21 | 55 | White | 1 carbonates | Soft | S |
| D | .46 | .26 | | do. | 1 carbonates | | S |
| A | 7.58 | .00 | | Dk. brown | 50-75 tremolite | | U |
| A-c | 4.30 | .00 | | Brown | 5 tremolite | | U |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|-------|--------------------------|-----------------------|------------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 46- A | 0.80 | 0.02 | | Lt. cream | 2 carbonates | Very soft | S |
| A-c | .76 | .02 | 81 | do. | Trace carbonates | | S |
| B | 1.16 | .16 | | Buff | 1 opaques | Soft | S |
| C | .74 | .16 | | Lt. cream | Traces | do. | S |
| 47- A | .36 | 5.43 | | White | 25-35 carbonates, tremolite | Hard | U |
| A-c | .34 | 3.02 | 30 | do. | 20 carbonates, tremolite | | U |
| B | .90 | .03 | | do. | 2 carbonates, tremolite | | S |
| C | .87 | .21 | | do. | 3 carbonates, tremolite | | S |
| 48- A | .63 | 9.44 | | Lt. cream | Essentially all tremolite | | U |
| A-c | .56 | 5.35 | 29 | Ivory | do. | | U |
| B | .78 | .91 | | do. | 2-3 rutile, carbonates, etc. | Std. | S |
| C | .48 | 6.23 | | do. | 50 carbonates, tremolite | | U |
| C-c | .49 | 3.40 | 26 | do. | 30 carbonates, tremolite | | U |
| 49- A | .72 | .97 | | Ivory | 2-3 carbonates | Soft | S |
| 50- A | .45 | 4.57 | | White | Probably calcined talc | Hard | U |
| 51- A | .89 | 2.02 | | do. | 5-10 carbonates, tremolite | Soft | Blend |
| A-c | .95 | 1.55 | 52 | do. | 2-3 carbonates, tremolite | do. | S |
| B | .26 | 2.74 | | do. | 15-20 carbonates, tremolite | do. | Blend |
| B-c | .28 | 1.25 | 73 | do. | 1 carbonates, tremolite | do. | S |
| C | .57 | 25.25 | | Gray | 75 carbonates, tremolite | Hard | U |
| D | .34 | 23.00 | | Tan | 50 carbonates, tremolite | | U |
| E | .24 | 9.17 | | White | 50 carbonates, tremolite | Hard | U |
| F | .47 | 9.85 | | Dk. cream | 50 carbonates, tremolite | | U |
| F-c | .54 | 2.75 | 51 | White | 10 carbonates, tremolite | Soft | Blend |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|--------------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 52- A | 1.35 | 0.04 | | Buff | Trace rutile, iron, etc. | Very soft | S |
| A-c | 1.37 | .08 | 91 | do. | do. | | S |
| B | 1.30 | .05 | | do. | Trace carbonates, iron stain | Soft | S |
| B-c | .92 | .02 | 85 | do. | do. | do. | S |
| C | 1.56 | .04 | | do. | do. | do. | S |
| C-c | 1.10 | .02 | 63 | Lt. cream | do. | do. | S |
| D | 1.66 | .04 | | Dk. buff | do. | Very soft | Blend |
| D-c | 1.66 | .04 | 88 | do. | do. | do. | Do. |
| E | 1.28 | .03 | | do. | do. | do. | Do. |
| F | 2.02 | .04 | | do. | 2-3 carbonates | Soft | Blend |
| F-c | 2.02 | .06 | 84 | Buff | 2-3 carbonates | do. | Do. |
| G | 1.64 | .03 | | Dk. buff | 1-2 carbonates | do. | Do. |
| G-c | 1.60 | .06 | 80 | Cream | 1-2 carbonates | do. | Do. |
| H | 1.34 | .03 | | Buff | 1 carbonates | Very soft | S |
| 53- A | 4.31 | .06 | | Brown | 25 tremolite, actinolite, etc. | | U |
| A-c | 2.67 | .04 | 63 | Lt. brown | 3-5 tremolite, actinolite | Std. | U |
| 54- A | 2.60 | .22 | | do. | 1-2 carbonates | Soft | Blend |
| A-c | 2.62 | .04 | 84 | do. | 1 carbonates | do. | Do. |
| B | .84 | 1.02 | | Ivory | 5-10 carbonates | do. | S |
| B-c | .84 | .76 | 90-95 | do. | 5-10 carbonates | do. | S |
| 55- A | .36 | 2.25 | | White | 2 carbonates | | Blend |
| A-c | .49 | .76 | 51 | do. | 2 carbonates | | S |
| 56- A | .76 | .28 | | Ivory | 2 carbonates | | S |
| 57- A | 1.63 | 5.41 | | Tan | 75 tremolite, quartz | | U |
| A-c | 1.59 | 3.64 | 51 | Buff | 50-75 tremolite, quartz | Hard | U |
| 58- A | 6.13 | .12 | | Brown | 20 magnetite, chlorite | | U |
| A-c | 3.13 | .07 | 64 | do. | 1-2 magnetite, chlorite | | U |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Fired color (Cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--------------------------------|------|--------------------------|-----------------------|--|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 59- A | 0.50 | 0.05 | | White | 1 tremolite, carbonates | Soft | S |
| B | .45 | .26 | | do. | 2 tremolite, carbonates | do. | S |
| 60- A | 1.10 | .32 | | Cream | 2-3 tremolite, carbonates | do. | S |
| B | 1.66 | .06 | | Buff | Essentially a chlorite (18.34 percent Al ₂ O ₃) | do. | U |
| 61- A | 1.08 | 1.30 | | Cream | 2-3 carbonates, chlorite | Soft | S |
| B | .96 | .15 | | Off-white | 1 carbonates, chlorite | do. | S |
| C | .89 | .12 | | Ivory | 1 carbonates, chlorite | do. | S |
| D | 1.89 | .26 | | Buff | Essentially chlorite (18.74 percent Al ₂ O ₃) | do. | U |
| 62- A | .73 | .07 | | White | 1 carbonates, chlorite | do. | S |
| B | 1.24 | .14 | | Cream | 1 carbonates, chlorite | do. | S |
| 63- A | 1.00 | .10 | | do. | 5 chlorite, carbonates | | S |
| 64- A | 2.51 | .13 | | Brown | Trace carbonates, chlorite | | Blend |
| A-c | 2.49 | .16 | 83 | Tan | Trace carbonates, chlorite | | Do. |
| 65- A | 2.79 | .64 | | do. | Essentially chlorite (18.16 percent Al ₂ O ₃) | Very soft | U |
| A-c | 1.46 | .14 | 13 | do. | Essentially chlorite (2.57 percent Al ₂ O ₃) | | U |
| B | 1.40 | .41 | | Ivory | 1 carbonates, rutile | | S |
| B-c | 1.17 | .20 | 72 | do. | Trace carbonates, rutile | | S |
| 66- A | .92 | .13 | | do. | 1 carbonate | | S |
| 67- A | 2.76 | .19 | | Dk. buff | 1-2 tremolite | | Blend |
| 68- A | .95 | .08 | | Buff | 1 carbonates, quartz | | S |
| B | .73 | .11 | | Cream | 2-3 carbonates, quartz | | S |

TABLE 2. - Results of tests on raw materials (Cont'd.)

| Sample No. | Assays, percent | | Weight, percent recovery | Field color (cone 10) | Mineral impurities, percent | Abrasion test | Rating |
|------------|--|-------|--------------------------|-----------------------|-------------------------------------|---------------|--------|
| | Fe ₂ O ₃ | CaO | | | | | |
| 69- A | 0.42 | 0.10 | | White | 1-2 tremolite | | S |
| 70- A | 1.50 | .11 | | Cream | 75-90 serpentine | | U |
| 71- A | .30 | 1.68 | | White | 15-20 carbonates, tremolite | Std. | S |
| 72- A | .35 | 3.35 | | White | 75 tremolite, quartz | Hard | U |
| A-c | .40 | .65 | 37 | do. | 40 tremolite, quartz | | S |
| B | .47 | 2.63 | | do. | 75 tremolite, quartz | | U |
| B-c | .49 | .90 | 32 | do. | 50 tremolite, quartz | | S |
| C | .38 | 4.25 | | do. | 75 tremolite, quartz | | U |
| C-c | Would not float | | | do. | | | U |
| D | .40 | 4.44 | | do. | 75 tremolite, quartz | | U |
| D-c | .36 | 1.22 | 29 | | 35 tremolite, quartz | | S |
| E | .29 | 11.68 | | Cream | 75 tremolite, quartz | | U |
| E-c | .32 | 7.27 | 13 | do. | 60 tremolite, quartz | | U |
| 73- A | 5.64 | .09 | | Brown | 3 magnetite | | U |
| 74- A | 5.76 | .88 | | do. | 40 magnetite, tremolite | | U |
| B | 6.24 | .20 | | do. | 40 magnetite, tremolite | | U |
| C | 5.72 | .52 | | do. | 40 magnetite, tremolite | | U |
| 75- A | .88 | .07 | | Cream | 1 apatite, carbonates | | S |
| 76- A | Not tested as raw material at Tuscaloosa, Ala. | | | | | | |
| B | | | do. | | | | |
| C | | | do. | | | | |
| D | | | do. | | | | |
| 77- A | 2.60 | .13 | | Tan | 50 feldspar, quartz, ilmenite, etc. | Hard | U |
| A-c | 2.24 | .05 | 71.6 | do. | 10 quartz, feldspar | | U |
| B | 2.05 | .03 | | | | | U |

TABLE 3. - Analyses of talc used by manufacturers

| | SiO ₂ | Al ₂ O ₃ | TiO ₂ | Fe ₂ O ₃ | CaO | MgO | KNaO | Ig. loss | |
|-------------|------------------|--------------------------------|------------------|--------------------------------|------|-------|------|----------|--------|
| Theoretical | 63.50 | | | | | 31.7 | | 4.8 | 100 |
| 1-A | 62.30 | 1.98 | 0.04 | 1.30 | 0.64 | 28.26 | 0.47 | 5.25 | 100.2 |
| 1-B | 58.06 | .85 | | 1.21 | .43 | 31.85 | 1.14 | 5.68 | 99.2 |
| 1-C | 59.30 | 1.15 | | 1.25 | .08 | 32.08 | .62 | 5.55 | 100.03 |
| 1-D | 58.70 | .68 | | 1.28 | .59 | 32.50 | .22 | 5.98 | 99.94 |
| 1-E | 60.05 | .45 | | 1.36 | .09 | 32.10 | .13 | 5.41 | 99.59 |

TABLE 4. - Rating of talc samples on basis of raw-material tests

Satisfactory substitutes for Sierra talc

| | | | | | |
|-------|-------|--------|--------|--------|--------|
| 1-G-c | 8-F | 18-A-c | 26-E | 42-B | 54-B |
| H-c | F-c | B-c | E-c | 43-A | B-c |
| I-c | G-c | 19-A-c | F | B-c | 55-A-c |
| J-c | H-c | C-c | F-c | C | 56-A |
| K-c | K | D | G | 44-A | 59-A |
| L-c | K-c | D-c | G-c | B-c | B |
| M-c | M | E-c | H | C | 60-A |
| N | N | F-c | H-c | D | 61-A |
| N-c | O | G | I | 46-A | B |
| O | 9-B-c | 20-C | I-c | A-c | C |
| O-c | C-c | C-c | J-c | B | 62-A |
| P | 12-A | D | M-c | C | B |
| P-c | A-c | D-c | 28-A-c | 47-B | 63-A |
| R-c | C | 21-D-c | 30-A | C | 65-B |
| S | C-c | E | 33-A-c | 48-B | B-c |
| S-c | 14-A | E-c | 34-B-c | 49-A | 66-A |
| T | C | F | 35-A | 51-A-c | 68-A |
| T-c | C-c | 22-B | A-c | B-c | B |
| 6-A-c | 15-A | 25-B-c | 36-A | 52-A | 69-A |
| B-c | A-c | C | A-c | A-c | 71-A |
| C-c | B-c | 26-A-c | 39-A | B | 72-A-c |
| 8-A-c | C-c | B | A-c | B-c | B-c |
| C-c | D | B-c | B | C | D-c |
| D-c | D-c | C | C | C-c | 75-A |
| E-c | E | C-c | C-c | H | |
| | F | | | | |

If blended with other talcs should be satisfactory
substitutes for Sierra talc

| | | | |
|--------|------|------|------|
| 8-L | 33-B | 51-B | 52-G |
| 9-C | C | F-c | G-c |
| D | 34-A | 52-D | 54-A |
| D-c | B | D-c | A-c |
| 12-E-c | 43-B | E | 55-A |
| 15-B | 44-B | F | 64-A |
| 22-A | 51-A | F-c | A-c |
| | | | 67-A |

TABLE 4. - Rating of talc samples on basis of raw-material tests (Cont'd.)

Unsatisfactory as substitutes for Sierra talc

| | | | | | |
|-----|------|------|------|-------|------|
| 1-F | 8-B | 16-A | 23-A | 32-A | 51-C |
| F-c | B-c | A-c | A-c | A-c | D |
| G | C | 17-A | B | 33-A | E |
| H | D | A-c | B-c | 37-A | F |
| I | E | 18-A | C | 38-A | 53-A |
| J | G | B | C-c | A-c | A-c |
| K | H | 19-A | D | B | 57-A |
| L | J | B | D-c | B-c | A-c |
| M | J-c | B-c | 24-A | C&D | 58-A |
| R | 9-A | C | A-c | C&D-c | A-c |
| U | A-c | E | 25-A | E | 60-B |
| 2-A | B | F | B | F | 61-D |
| A-c | 10-A | 20-A | 26-A | 40-A | 65-A |
| B | A-c | A-c | D | 41-A | A-c |
| B-c | B | B | D-c | A-c | 70-A |
| C | B-c | B-c | J | B | 72-A |
| 3-A | 11-A | E | K | B-c | B |
| A-c | A-c | F | K-c | 42-A | C |
| 4-A | 12-B | G | L | A-c | C-c |
| A-c | D | 21-A | L-c | 45-A | D |
| B | D-c | A-c | M | A-c | E |
| B-c | E | B | 27-A | 47-A | E-c |
| 5-A | F | B-c | A-c | A-c | 73-A |
| A-c | F-c | C | 28-A | 48-A | 74-A |
| 6-A | 13-A | C-c | 29-A | A-c | B |
| B | A-c | D | A-c | C | C |
| C | 14-B | G | 31-A | C-c | 77-A |
| 7-A | D | | A-c | 50-A | A-c |
| A-c | D-c | | B | | B |
| 8-A | C | | B-c | | |

Appendix

In the course of the search for domestic sources of talc suitable for steatite ceramics, widespread interest was aroused, and many inquiries were received as to the exact procedures in making evaluations. Some of these inquiries were from laboratories or manufacturers who preferred to do their own testing at the plant and some from others who wished to make tests in the field as a time-saving expedient. In view of the interest expressed in methods, the following test procedures are suggested for evaluation of talc.

Testing Methods

Field Testing Procedure

The field tests are designed only to eliminate a number of minerals likely to be mistaken for talc. Evaluation as to grade requires careful laboratory analyses that cannot be made with the usual field equipment.

Color

When talcs are used without heat processing, the color in the raw state is important. Where used in ceramics, however, the color in the raw state has no significance unless it is quite dark. It may then indicate possible low grade, due to its iron content. Theoretically, if a talc has no impurities, it should be white. However, since such undesirable impurities as carbonates and tremolites are white also, not much attention should be given to color alone.

Floatability

The commonest minerals likely to be mistaken for talc are pyrophyllite and chlorites, because they are soft and greasy to the touch. Also, talcs are almost invariably mixed with carbonates, chlorites, serpentines, tremolite, and other amphiboles, sometimes to such an extent that it may be a question whether the mixture is even predominantly a talc.

An easy way to differentiate a comparatively pure talc from nontalcs and those talcs with very high impurities is the use of a floatability test. Talc is one of four common minerals that possess what may be termed "inherent floatability." Pyrophyllite, graphite, and molybdenite also have a similar property. That is, they are water-repellent and will attach themselves to air bubbles when agitated in water without the use of a collecting agent, needing only a frothing agent to cause formation of bubbles. Graphite and molybdenite are so distinctly dark gray or bluish gray that there will be no mistake in their identification by visual inspection. Pyrophyllite, however, needs identification by other means.

The procedure is to grind a small quantity of the material (2 or 3 pinches are sufficient) to a powder. If a mortar is not available, a small iron cap which fits loosely over the end of a field hammer makes an excellent mortar, the flat end of the hammer serving as a pestle.

Use a small bottle or jar, half full of water, and add 1 drop of pine oil.^{8/} Since the frothing agent (pine oil) must be emulsified, shake the bottle vigorously. If a wide-mouth jar is used add the ground sample to the emulsion, and shake again. If not, pour into a beaker or cup, and whip with a spatula or knife blade until a froth collects. The amount of froth may be increased if air is introduced into the liquid near the bottom of the bottle by blowing vigorously through a tube. If a tube with a small orifice is used, the bubbles will be small and numerous.

If the sample is talc with little impurity, the bubbles will pick up the particles, and the froth will be heavily laden. With nontalcs, or where the impurities are excessive, only a few particles will be entrapped, and the bubbles will appear quite clear.

Determination of Grade

Although it is possible to obtain a rough idea of the amount of iron present by blowpipe analysis in the field, the calcium and alumina cannot be determined this way. Since a calcium determination should always be made in the laboratory it is best to determine the iron at the same time, and thus have equally accurate results.

Laboratory Procedure

Testing in the laboratory involves the same steps as those mentioned in the field testing, that is, an identification of the talc mineral and an evaluation as to grade. A further step can be taken by determining whether or not an off-grade talc is amenable to beneficiation.

Upon receipt of a talc sample, a visual examination is usually of value. Many talcs contain veins of quartz, iron-bearing minerals, or other impurities. Cobbing and hand-picking should be considered. A ground sample direct from a mill is not as desirable as the crude ore.

The testing procedure to be used in evaluation follows the outline in figure 1. Preparation of the sample for testing is begun by reduction to 1/2-inch in a jaw crusher. If the sample is large (200 pounds is preferred), a 25-pound sample should be cut out by riffing or quartering. The remainder is put aside as a source of material for body tests if the preliminary tests are satisfactory.

The 25-pound sample is then stage-ground through 20-mesh by means of a roll crusher. The sample should then be thoroughly mixed and cut samples taken for the various tests.

^{8/} Pine oil may be obtained at any drugstore. Other frothing agents such as the higher alcohols supplied by American Cyanamid Corporation may be used. These or other frothers probably could be obtained from any mill using the flotation process, since only a very small amount is necessary for a large number of tests.

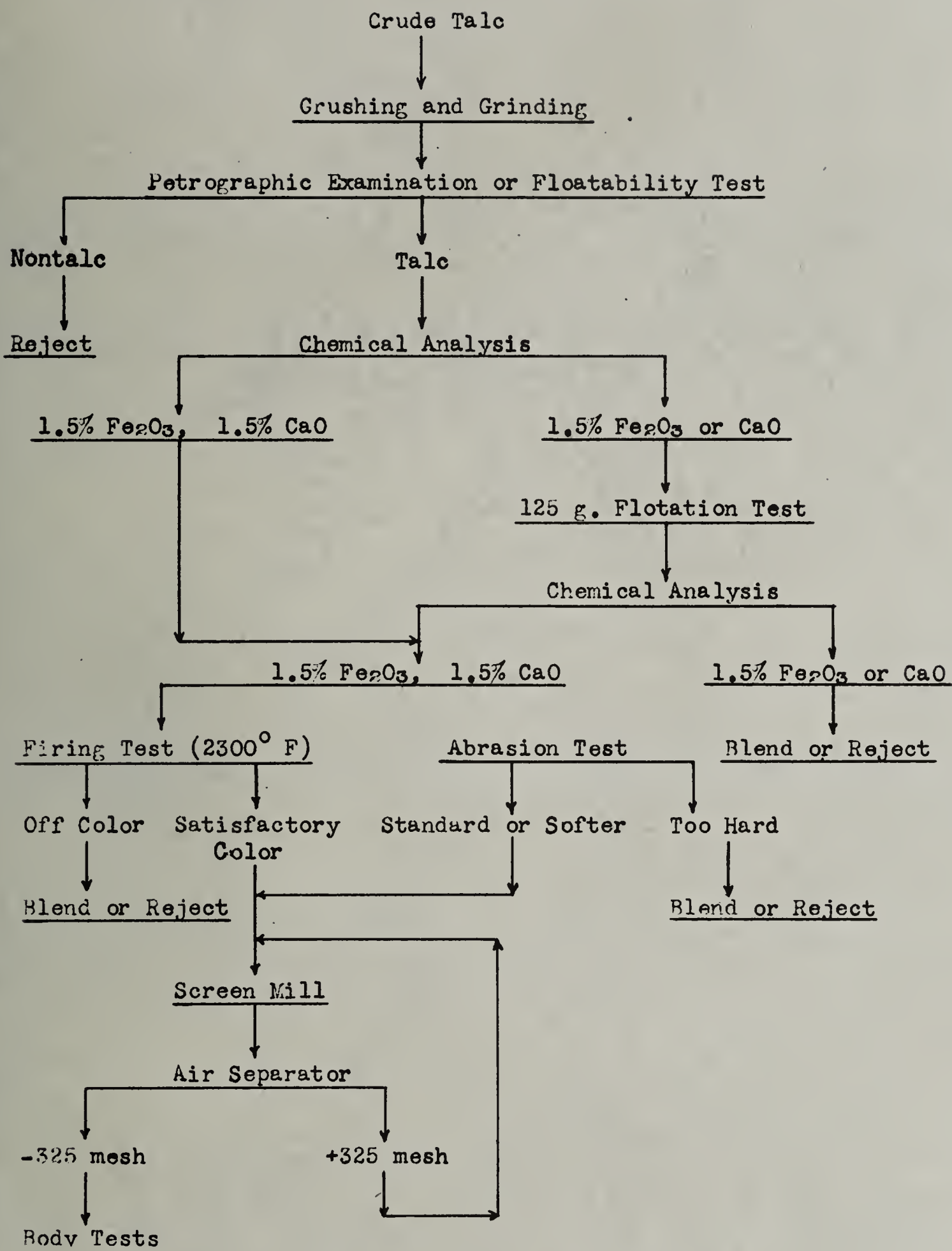
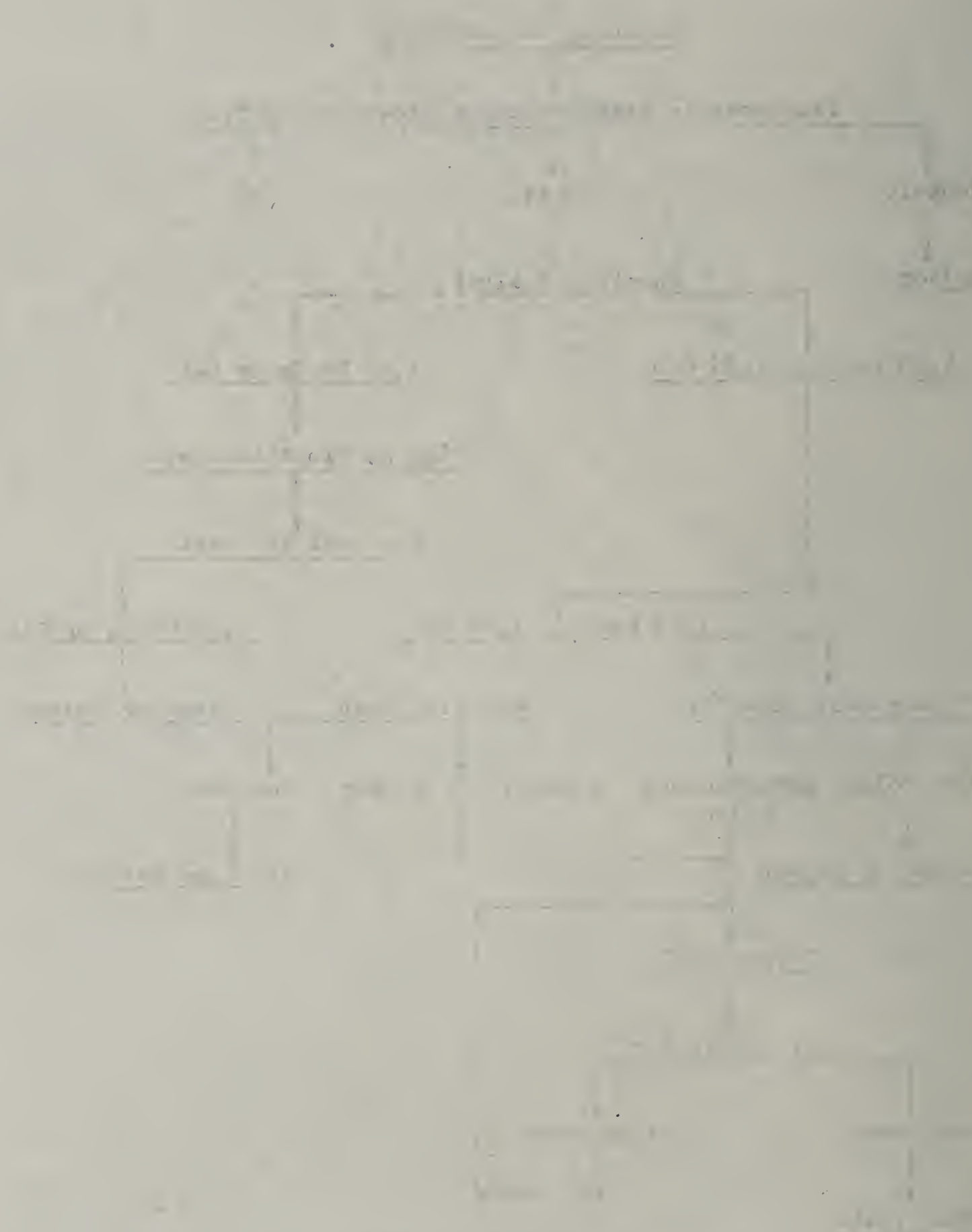


FIGURE 1.- Laboratory Procedure



Next, a 75-gm. sample is ground through 65-mesh with a mortar and pestle. The undersize is screened out at frequent intervals. After mixing thoroughly, a small portion (about 5 gm.) is cut out and ground through 100-mesh for petrographic analysis; a small plaque, about 1 inch by 2 inches, is made up of about 25 gm. for a firing test; and a 10-gm. sample is used for chemical analysis. The remainder of the 65-mesh product is kept as a stock sample and for floatability tests.

Petrographic Examination

Much time is saved if the sample can be examined by a competent petrographer. Many manufacturers make these examinations as a routine procedure.

The petrographer can determine whether or not the material is talc, what nontalc minerals are present, and in what approximate percentage. If a considerable percentage of alumina-bearing minerals is present, the need of a chemical determination for Al_2O_3 is indicated; otherwise, none is necessary.

The type of lime-bearing mineral and also the manner in which the iron is present may determine whether or not a talc is amenable to beneficiation, and the petrographic examination is of great assistance in this respect. Specks of iron minerals cause dark specks in the fired product. Stains of iron oxide uniformly distributed may give satisfactory fired products. Some green talcs contain a considerable amount of iron as part of the talc mineral itself.

Although these various points may be worked out by the other methods, hours of time may often be saved by a brief examination with the petrographic microscope.

Chemical Analyses

The chemical determinations for the lime, iron, and alumina present are made according to regular standard procedures to be found in any text on quantitative analysis. The accuracy need not be beyond the first decimal place.

Flotation Tests

Many talcs, particularly those high in lime, can be beneficiated to grade by flotation. The procedure described below is not a hard-and-fast one, but has been found to be simple and suited to a wider variety of talcs than other methods. Grinding only to the liberation size and using more complicated reagent charges for maximum recovery should be an undertaking for the talc producer. The authors feel that such detailed work is too lengthy for preliminary testing. The method suggested is as follows:

A 125-gm. charge of minus 20-mesh material is wet-ground in a small pebble mill in short stages. The minus 200-mesh fraction is screened out after each stage. Following reduction, the excess water is filtered out and after a brief conditioning period with 0.3 pound of pine oil per ton of material, the charge is floated in a 250-gm.

mechanical-type machine. The pulp consistency is approximately 14 percent solids. Other frothing agents, such as the higher alcohols, may be substituted for pine oil.

The concentrate from the roughing cell is cleaned twice in a 500-gm. cell of the same type. The products are filtered and assayed for Fe_2O_3 and CaO . If the concentrate from the cleaning machine is still too high in impurities, it can be considered for a blend or rejected.

Samples that respond satisfactorily to flotation and those that are within grade as received are tested for firing and abrasion characteristics.

Heat-Treating Test

For the firing test, a small dried plaque (about 1 inch wide by 1-1/2 inches long by 1/4 inch thick) is fired to 2,300° F. in 6 to 8 hours. An electric muffle furnace is admirably suited for this purpose, though other types will serve. To be acceptable, the plaque must fire no darker than cream or light buff. Darker samples may serve as blends; otherwise they should be rejected. Excessive shrinkage, cracking, and warping should be noted. Lack of fluxing constituents in a talc of the platy variety may cause swelling or disintegration of the plaque. Swelling is not necessarily harmful, though it usually indicates that the talc will be somewhat more refractory than the standard California talc and will require adjustment of the body composition if used. The relative refractoriness may be checked by obtaining PCE values (softening points), a routine procedure with many manufacturers.

Abrasion Test

Samples that meet other specifications should be tested for abrasive qualities. A highly abrasive material is not suited for use in steatite ceramics, since it causes undue wear on the dies used in processing the ware. An absolute value for abrasion is not practical, but by using a typical commercial California talc as a standard, other talcs can be classified into low, standard, and highly abrasive groups. The device used for this purpose was originally developed for testing the abrasive qualities of dentifrices.^{9/} It consists of a revolving plate filled to a depth of about 1 inch with wax. In a groove cut in the wax, a talc slurry of approximately 50 percent solids is placed. The abrasion is measured by the loss in weight of two cadmium blocks held stationary in the moving slurry for 2 hours by externally mounted arms. The positions of the shoes are exchanged at the end of 1 hour. The talc used in this test should be ground to pass a 325-mesh screen; otherwise, the results will not be comparable.

^{9/} Smith, Ralph W., Machine for Testing Dentifrice Abrasion: Ind. and Eng. Chem., vol. 12, July 15, 1940, p. 419. Details of construction are given in this article.

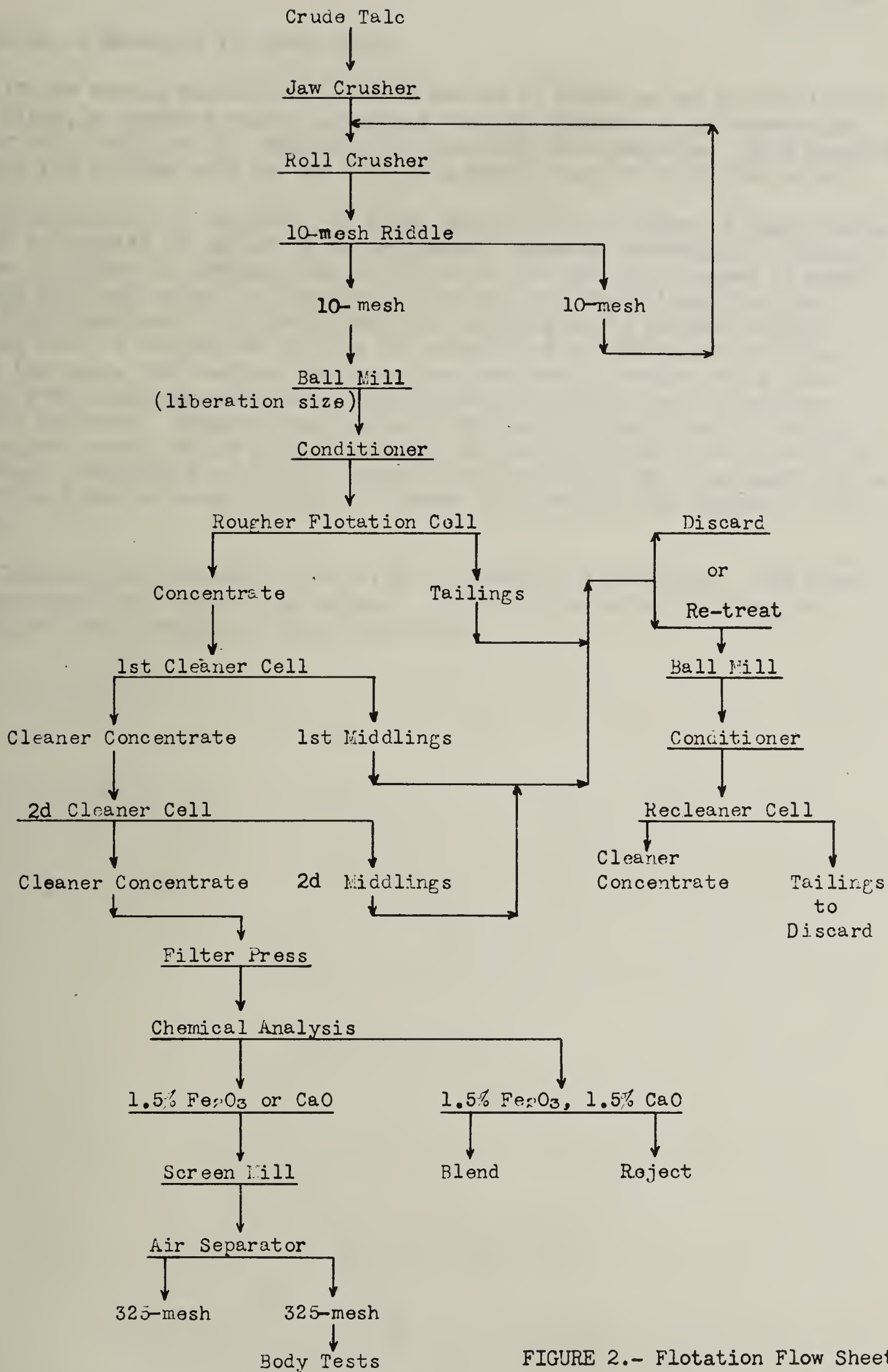
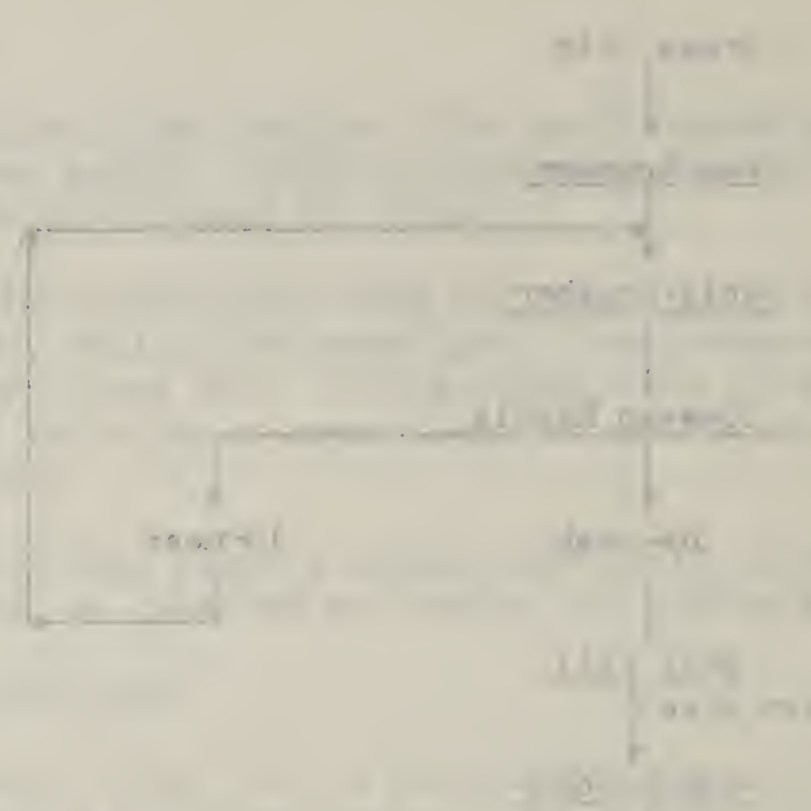


FIGURE 2.- Flotation Flow Sheet.



Flotation of Material for Body Tests

If the sample passes the previous series of tests or has possibilities as a blend, a 50-pound sample is ground through 325-mesh in a screen-type hammer mill, with an air separator for removing the undersize. This material is used for further work on the talc as a constituent of steatite bodies.

If flotation is necessary to bring the talc up to grade, a sample large enough to provide 50 pounds of concentrate is treated according to the procedure in figure 2. Preparatory to flotation the talc is crushed to pass 10-mesh and then ground in batches in a large, porcelain-lined ball mill with flint pebbles. Pulp consistency in grinding is 50 percent solids. Milling time is controlled to give the particle size necessary for liberating the talc. By feeding the ground batches into a conditioning tank fitted with a high-speed mixer, a continuous flow into a unit flotation cell is achieved. Reagents are added in the conditioner, pine oil being used alone, except where it is necessary to modify a voluminous froth with kerosine. Roughing flotation is carried out in a pulp of 15 percent solids. The froth from the roughing run is cleaned in a second step similar to the first.

Tailings and the middlings can be re-treated if necessary. The final concentrates are filtered and assayed. If found satisfactory, they are ground for body testing as described above.

PART 2. - CERAMIC BODY TESTS

In initial studies of domestic talc for radio insulator manufacture, the Bureau of Mines used chemical and petrographic analyses as criteria of the value of new talcs. These were based upon the recommendations of industrial users of steatite-grade talc and upon the available literature. However, experience indicates the lack of complete coordination between chemical oxide analysis and steatite insulator production and service requirements. It was decided, therefore, to substitute the new talc samples for White Mountain Mine No. 3 Sierra talc, a satisfactory commercial product, in a steatite test body and to compare the physical properties of the fired samples with those of the Sierra talc.

In all, 64 samples submitted by commercial talc producers or beneficiated at the Southern Experiment Station were substituted for Sierra talc in a cone-14 test body, and the shrinkage, absorption, mechanical strength, and dielectric properties were compared with the corresponding values for the standard body. Shrinkage values between 6 and 10 percent, an absorption less than 0.1 percent, and a Q value equal to that of the standard body within the experimental error were adopted as specifications for an acceptable talc. Thirty-one talcs, 8 of which were beneficiated by flotation, were satisfactory substitutes for Sierra talc if classified on the basis of the above specifications. Seven of these talcs had shrinkages equal to that of Sierra within ± 1 percent. Twenty-seven samples were unsatisfactory substitutes for Sierra talc in a cone-14 body wither because of differences in vitrification temperature or slightly inferior dielectric properties. Six samples were entirely unsatisfactory because of high iron content or abrasiveness.

The acceptable eastern talc samples were two flotation products from New York, three flotation concentrate samples from Alabama, two untreated New York talcs, and one sample each from North Carolina and Virginia. The plastic Alabama talc had a high shrinkage (10 percent) and could be used only as a blend material by established steatite manufacturers. Other New York talcs were more refractory than the Sierra talc but might be used with a slightly higher firing temperature, if the abrasive, lime-bearing compounds were removed by flotation. An adequate reserve of uniform material is essential before a talc will be considered by any steatite manufacturer.

Testing Methods

Preparation of Body

The following test body was used as the standard:

| | <u>Percent</u> |
|-----------------------|----------------|
| Sierra talc | 90 |
| Edgar Florida kaolin. | 5 |
| Minpro 69-31 feldspar | <u>5</u> |
| | 100 |

This mixture was ball-milled with an equal weight of water for 30 minutes in a porcelain-lined, 14-inch-diameter mill, using 50 pounds of 2-1/2-inch flint

pebbles and 10 pounds of 1-inch pebbles. The slip was then screened to pass 100-mesh, dried at 90° C., and crushed to 14-mesh. A solution of 2 percent gum arabic in 15 percent water, both based on the weight of talc body, was incorporated thoroughly into the dry body by repeated hand screenings through 10-, 12-, 14-, and 16-mesh screens. The dampened body was divided into two fractions, a 90-percent portion being dried at 65° C. and then remixed with the 10-percent damp portion by repeated hand screenings to minimize contamination. The 16-100-mesh fraction of this material was pressed at 4,000 p.s.i. to give 4-inch-diameter by 3/16-inch-thick round tile and 6-inch square tile approximately 1/4 inch thick. Round transverse-strength specimens, 1 inch by 6 inches, were made by plastic extrusion in a small vacuum auger machine. The specimens were placed on a bedding of Ottawa sand and fired to cone-14⁵ to 14^d in 24 hours including a 5-hour soaking period in an electric Globar-fired kiln of 20-inch by 28-inch by 30-inch inside dimensions. The maximum temperature was approximately $1,370^{\circ}$ C. under these conditions.

Standard Sierra-talc body samples were placed in each firing and tested for uniformity of firing, not only for different parts of the kiln, but for the successive firings.

Dielectric measurements, mechanical strength tests, and the conventional ceramic tests were made on the specimens fired to cone 14. Since the present investigation was essentially concerned with finding available substitutes for the Sierra California talc, the properties of bodies containing other talcs were compared directly with the standard Sierra mixture.

Dielectric Properties

Several ways are used to express the dielectric characteristics of an insulator. The most common measurement is the power factor, or ratio of the resistance to the impedance of the insulator. A lower power factor is indicative of an efficient insulator. The Q-factor is not as widely used, but is easier to visualize, since it increases as the insulator becomes more efficient. Q-factor is defined as the ratio of reactance to resistance and practically equals the reciprocal of the power factor in the range of values studied. The total energy loss in a high-frequency circuit is proportional to the loss factor, which is the product of the power factor and the dielectric constant.

The American Standards Association war standard on ceramic radio-insulating materials uses the loss factor of these materials after immersion in distilled water as a measure of dielectric properties. Regardless of the method used to designate the efficiency of the insulator, the same experimental data were obtained by means of a Q meter (type 100-A, serial number 379, manufactured by the Boonton Radio Corporation, Boonton, N. J.). This commercial instrument is designed to measure capacity and Q value in the frequency range from 50 kilocycles to 50 megacycles. The experimental error in using this instrument is approximately ± 10 percent, although for high Q values of approximately 1,500, the experimental error is about ± 20 percent and increases rapidly with higher values.

The tiles were dried at 110° C. and cooled in a desiccator. Lead foil 0.001 inch thick was then applied to both surfaces of the 4-inch round disks, using a thin layer of petroleum jelly as an adhesive. The surface was worked smooth by rubbing with the thumb radially outward to remove all air bubbles and excess petrolatum. The metal foil was then cut flush with the edge and any surplus petroleum jelly on the sides of the disk carefully removed. When the test was to be made on a wet specimen, the samples were soaked in distilled water under a vacuum of less than 20 mm. of mercury for 1 hour and then remained in water at atmospheric pressure for at least 24 hours before testing. The tiles were wiped with dry, absorbent cloth, and the lead foil was applied with petrolatum. Measurements were completed within 4 minutes of the time that each tile was removed from the water.

In making the measurements no guard electrodes were used, and the disk was supported in a U-shaped steatite stand between two centrally applied, threaded electrodes; the stationary one was 1/2 inch in diameter and the movable electrode 1/8 inch in diameter. The experimental arrangement and calculations were similar to those prescribed by the American Society for Testing Materials specifications,^{10/} using the simple capacitor circuit without shield or guard rings and the calibrated Q range of the Q meter instead of voltage measurements.^{11/} The circuit was tuned to resonance with and without the test disk in the circuit by changing the capacity of the system. In each case the test holder was left in the circuit, and its capacity and dielectric loss were disregarded. The capacity of the specimen was determined directly by noting the loss in resonance capacity when it was inserted in the circuit. It should be noted that the measured dielectric properties depended to some extent on such atmospheric conditions as relative humidity and temperature. All measurements were made at a frequency of 1 megacycle, as specified by the American Standards Association war standard. No edge correction was applied in calculating the dielectric constant according to the formula

$$K = \frac{C \times t}{0.224 \times A},$$

wherein K = dielectric constant,
 C = capacity in mmf.,
 t = thickness in inches,
 A - area in square inches.

The thickness measurement was the average of the values at five points determined with a micrometer caliper. Any piece that showed thickness variations of more than ±10 percent from the average was rejected. Areas were calculated from the average diameter measured with micrometer calipers. Dielectric tests were made on five specimens of each body, except in cases where insufficient talc was available to prepare five specimens.

^{10/} American Society for Testing Materials, Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials: A.S.T.M. Standard D150-41T.

^{11/} Boonton Radio Corporation, Instructions and Manual of Radio Frequency Measurements for Q Meter Type 100-A: Boonton, N. J., 1941.

Dielectric tests on 6-inch square tiles of most of the talcs were made at the Naval Research Laboratory, using the parallel substitution method of susceptance variation. The measuring equipment consisted of the following:

1. 1,000-kilocycle, crystal-controlled, master oscillator power amplifier, assembled by the Naval Research Laboratory.
2. Naval Research Laboratory standard inductance No. 6.
3. General Radio quartz-insulated, precision condenser, type 722Q, serial 460.
4. General Radio vacuum-tube voltmeter, type 726-A, serial 1483.

Ceramic Properties

The water absorption was determined on the unbroken bisque tiles. Samples were dried at 110° C. and cooled in a desiccator before the dry weight was measured to a precision of 0.001 gram. The samples then were placed in a container and put under vacuum in a bell jar for 20 minutes. Distilled water was introduced into the container while still under vacuum, and the specimens were soaked for 1 hour before removal from the vacuum. The tiles were wiped carefully with a dry absorbent cloth and weighed immediately.

$$\text{Percent water absorption} = \frac{\text{gain in weight}}{\text{dry weight}} \times 100.$$

All shrinkage data were based on the original mold size. Two diameters, normal to each other, were measured by means of micrometer calipers graduated to 0.001 inch, and the average value was used in determining the linear shrinkage as read from a shrinkage chart. Shrinkage and absorption data were based on the average of at least five specimens.

Mechanical Properties

Modulus of rupture was determined by breaking the vacuum-extruded 1- by 6-inch cylindrical bars. The test machine has a 5-inch span and uses lead shot at the end of an 8"1 lever arm.^{12/} The average strength was based on six specimens, and any specimens varying more than 20 percent from the average were rejected.

Impact tests were made by supporting the 4-inch round specimens at three points and striking the center of the disk with a 5-ounce hammer of a pendulum-type impact machine graduated in units of 0.01 foot-pound.^{13/} The first

^{12/} American Ceramic Society, Committee on Standards, 1927-28, A-15, Transverse Strength Apparatus: Jour., June 1928, pp. 514-517.

^{13/} Improved model of Bureau of Standards chinaware impact testing machine described by Wray, G. W., and Brand, C. M., Comparative Tests of Chinaware Using Two Forms of Testing Machines: Jour. Am. Ceram. Soc., vol. 12, November 1929, pp. 716-724.

impact was 0.05 foot-pound, and successive strokes were increased by 0.01-foot-pound increments until the specimen cracked. The values are only relative but are comparable to each other. At least five specimens were used for each talc.

Steatite Body Specifications

In the Bureau of Mines physical tests, all talcs were substituted for the standard commercial Sierra talc (1-A) in a cone-14 body. This talc was recognized as the best available for high-frequency insulation manufacture at the beginning of the war. The following tentative specifications were adopted for the test bodies.

1. Absorption. - The body should not absorb moisture or be affected by exposure to water. An absorption of 0.1 percent was adopted as the permissible maximum. The recent American Standards Association war standard has replaced this water-absorption test by a dye-penetration test under pressure.

2. Shrinkage. - The standard body mixture containing 90 percent of the new talc should have a linear shrinkage of 6 to 10 percent to be satisfactory. The approved Sierra talc body had an average of 7.4 percent, with a range of ± 0.8 percent.

3. Modulus of Rupture. - The American Standards Association war standard, which requires minimum flexural strength of 3,000 pounds per square inch, was used.

4. Dielectric Properties. - The loss factor of ceramic insulators can vary widely and still be satisfactory, depending on the use for which the insulator is intended. The American Standards Association war standard now specifies six grades, as follows:

| Grade | L-1 | L-2 | L-3 | L-4 | L-5 | L-6 |
|---------------------|-------|-------|-------|-------|-------|-------|
| Maximum loss factor | 0.150 | 0.070 | 0.035 | 0.016 | 0.008 | 0.004 |

The test procedure calls for the determination of dielectric properties after 48 hours immersion in distilled water. The talcs tested were all fired to cone 14 rather than to the correct vitrification temperature for each individual sample. Because a very slightly porous body will lead to a more marked increase in the loss factor of a wet specimen than of a dry one, it was thought advisable to use the dry dielectric properties in the preliminary classification of the talcs. The loss factor is approximately equal to ratio dielectric constant/Q-factor. As the dielectric constant of the experimental body, which can be classed as L-3, remained comparatively constant except for very porous bodies, the Q-factor, which rises with increased dielectric efficiency, can be used instead of the loss-factor as a criterion of high-frequency electrical characteristics. The Q-factor of any sample should be the same as that of the standard sample within the experimental error of ± 10 percent. A Q-factor of 220, or higher, determined at 1 megacycle, for the 4-inch disk was considered satisfactory.

5. Impact Tests. - The impact test data are relative but comparable with the value for the standard talc. Impact values of 0.12 foot-pound or higher were acceptable. The standard Sierra body had an average value of 0.15 with a variation of ± 0.02 .

Experimental Data

Cone-14 Tests

The data are summarized in tables 5 to 8. For convenience in comparison of the data, the material is divided into two sections - ceramic and electrical data. Table 5 summarizes the ceramic properties, shrinkage, absorption, fired color, strength, workability, and impact resistance. Table 6 gives the dielectric data obtained by measuring 4-inch round tiles on the Q meter at the Electrotechnical Laboratory. The dielectric test data for 6-inch square tiles obtained from the Naval Research Laboratory are contained in table 7.

Some talc samples did not contain enough material to make 6-inch square tiles. The Q-factors for the larger tiles are generally higher than those obtained at Norris and may be more accurate because of the more refined electrical testing equipment used by the Navy. However, when the Q-factors of the various talcs are compared with those of the standard Sierra talc, the same proportionate relationships usually hold for both the Norris Q-meter measurements and the more precise Naval Laboratory measurements. This qualitative comparison with the Sierra talc is the only standard adopted for dielectric properties in this investigation.

Cone-12 Tests

If only a cone-14 test body were used to compare the behavior of various talcs with Sierra talc, the question might arise whether the results were specific for this particular ceramic mixture or whether they applied in general to other mixtures vitrifying at other temperatures. For this reason a different body mixture was prepared, using alkaline-earth fluxes instead of feldspar and vitrifying at cone 12 instead of cone 14. This body had the following composition:

| | <u>Percent</u> |
|----------------------|----------------|
| Talc | 78.5 |
| Edgar Florida kaolin | 5.0 |
| Barium carbonate ... | 14.5 |
| Calcium carbonate .. | 2.0 |
| | <u>100.0</u> |

Where enough talc was available the test talc was incorporated into this cone-12 test mixture, and 4-inch round tile were made.

TABLE 5. - Ceramic properties of standard talc bodies fired to cone 14

| Sample No. | Fired color | 4-inch round | | 6-inch square | | Modulus of rupture, (p.s.i.) | Workability | Impact strength, ft.-lb. | Rating ² / |
|------------|---------------|-----------------------------------|---------------------|-----------------------------------|---------------------|------------------------------|-------------|--------------------------|-----------------------|
| | | Shrinkage, percent ¹ / | Absorption, percent | Shrinkage, percent ¹ / | Absorption, percent | | | | |
| 1-A | Gray cream | 7.0 | 0.05 | 7.8 | 0.035 | 10,200 | Good | 0.15 | Std. |
| I-c | do. | 8.8 | .020 | 8.7 | .018 | 15,100 | Fair | .12 | S |
| K-c | Lt. gray | 9.7 | .035 | 8.1 | .03 | 16,300 | Good | .13 | Blend |
| M-c | do. | 8.5 | .046 | 8.6 | (3/) | 15,000 | do. | .13 | S |
| P | Ivory | 8.4 | .106 | 8.2 | .65 | 8,300 | Poor | .15 | S |
| 6-B-c | Lt. gray | 5.8 | .50 | 5.6 | .60 | - | Fair | .16 | Ref. 8/ |
| C | Ivory | 6.8 | .031 | 6.6 | .043 | 5,600 | Good | .16 | Blend |
| 8-C-c | White | 7.3 | 1.14 | 5.4 | 4.60 | 4,200 | Fair | .13 | Ref. |
| E-c | do. | 4.7 | 6.30 | 5.0 | 8.15 | 3,800 | do. | .15 | Do. |
| J | do. | 5.40 | 10.9 | (5/) | (5/) | - | do. | .11 | Do. |
| K | do. | 8.35 | .044 | - | - | - | do. | .12 | Blend |
| 9-C | Sand | 7.10 | .039 | 6.9 | .039 | 9,000 | Good | .15 | Blend |
| C-c | do. | 6.3 | 1.56 | 6.0 | 1.48 | 3,000 | Fair | .14 | Ref. |
| D-c | Gray ivory | 6.45 | .029 | 6.9 | .028 | 6,500 | Good | .16 | Blend |
| 10-B-c | Chocolate | 6.1 | .015 | (5/) | (5/) | - | do. | .12 | U |
| 15-C-c | Lt. cream | - | - | 10.5 | .05 | 8,700 | do. | - | S |
| E-c | Ivory, specks | 9.5 | .009 | 9.3 | .065 | 10,300 | Fair | .15 | S |
| F-c | White | 10.8 | .038 | 9.8 | .068 | 14,750 | do. | .14 | S |
| 19-G | White, specks | 7.4 | .031 | 8.3 | .020 | 9,900 | do. | .14 | S |
| 20-D-c | White | 5.3 | 6.88 | - | - | 4,700 | do. | .11 | Ref. |
| E | Lt. ivory | 13.4 | (4/) | 12.2 | (4/) | - | do. | - | Over ⁴ / |
| F | do. | 9.45 | .071 | 9.45 | .092 | 7,700 | do. | .21 | S |
| 26-I-c | do. | 9.55 | .027 | 9.4 | .027 | 8,800 | Good | .17 | S |
| 31-B | Lt. cream | - | (4/) | - | (4/) | - | do. | - | Over |
| 38-A | White | 9.6 | 6/.18 | (7/) | (7/) | - | do. | .13 | Do. |
| C&D | do. | - | (4/) | - | (4/) | - | Fair | - | Do. |

Note: See footnotes on p. 50.

TABLE 5. - Ceramic properties of standard talc bodies fired to cone 14 (Cont'd.)

| Sample No. | Fired color | 4-inch round | | 6-inch square | | Modulus of rupture, (p.s.i.) | Workability | Impact strength, ft.-lb. | Rating ² / |
|------------|-----------------|-----------------------------------|---------------------|-----------------------------------|---------------------|------------------------------|-------------|--------------------------|-----------------------|
| | | Shrinkage, percent ¹ / | Absorption, percent | Shrinkage, percent ¹ / | Absorption, percent | | | | |
| 39-A-c | White | 8.7 | 0.042 | 8.4 | 0.023 | 15,400 | Fair | 0.16 | S |
| C | Cream, specks | 6.5 | 6/.065 | 6.1 | 6/.055 | 11,300 | do. | .15 | Blend |
| 43-B | Gray ivory | 9.9 | .021 | 9.6 | .024 | 14,000 | Good | .13 | S |
| C | Lt. cream | 7.5 | .06 | 7.4 | .05 | - | Fair | .12 | S |
| 44-C | White | 8.9 | .028 | 8.8 | .025 | 12,800 | Good | .14 | S |
| D | do. | 8.5 | .027 | 8.2 | .027 | 9,600 | do. | .13 | S |
| 46-A | do. | 8.4 | .011 | 7.6 | .030 | 14,800 | do. | .18 | Blend |
| 47-A | Lt. cream | 8.2 | .054 | 7.6 | .04 | 8,200 | do. | - | Do. |
| B | Lt. tan | 9.7 | 5.80 | (7/) | (7/) | - | Fair | .14 | Ref. |
| C | White | 8.15 | 1.15 | (7/) | (7/) | - | do. | .14 | Ref. |
| D | do. | 13.7 | .09 | - | (7/) | - | do. | .14 | U |
| 48-A | Cream | 10.2 | (4/) | - | (4/) | - | do. | .17 | Over |
| B | White | 7.5 | .040 | 6.7 | .035 | - | Good | .11 | S |
| C | do. | - | (4/) | - | (4/) | - | do. | .16 | Over |
| 49-A | Lt. ivory | 7.85 | .009 | 7.7 | .034 | - | Fair | .16 | S |
| 50-A | White | 19.5 | 6/.31 | (7/) | (7/) | - | Poor | - | U |
| 51-A | Lt. cream | 9.8 | 6/.043 | 9.7 | 6/.048 | - | Fair | .18 | Blend |
| A-c | do. | 9.6 | .031 | 9.0 | .031 | 9,000 | do. | .15 | S |
| B | White | 8.4 | 6/.040 | (7/) | (7/) | - | do. | .13 | S |
| F-c | Ivory | 9.65 | .033 | 9.45 | .022 | 11,000 | do. | .16 | S |
| 52-E | Lt. cream | 10.2 | .018 | 9.75 | .008 | 13,000 | Good | .17 | S |
| F | Lt. tan, specks | 9.35 | .013 | 9.05 | .006 | 16,100 | Fair | .20 | S |
| G | Cream | 9.7 | .011 | 9.50 | .010 | 15,600 | Good | .16 | S |
| H | Lt. gray | 9.45 | 6/.015 | 9.20 | .017 | 11,800 | Fair | .14 | S |
| 53-A | Dk. brown | 4.4 | .25 | (5/) | (5/) | - | do. | .09 | U |
| A-c | Brown | 5.6 | 1.20 | (7/) | (7/) | - | do. | .11 | U |

Note: See footnotes on p. 50.

TABLE 5. - Ceramic properties of standard talc bodies fired to cone 14 (Cont'd.)

| Sample No. | Fired color | 4-inch round | | 6-inch square | | Modulus of rupture, (p.s.i.) | Workability | Impact strength, ft.-lb. | Rating ^{2/} |
|------------|-------------|----------------------------------|---------------------|----------------------------------|---------------------|------------------------------|-------------|--------------------------|----------------------|
| | | Shrinkage, percent ^{1/} | Absorption, percent | Shrinkage, percent ^{1/} | Absorption, percent | | | | |
| 54-A | Lt. brown | 8.2 | 0.022 | (7/) | (7/) | 10,200 | Poor | 0.15 | Blend |
| B | Lt. ivory | 8.3 | .040 | (7/) | (7/) | - | Good | .13 | S |
| 55-A | do. | 8.7 | .022 | (7/) | (7/) | - | do. | .16 | S |
| 56-A | Cream | 7.95 | 1.52 | (7/) | (7/) | - | Fair | .15 | Ref. |
| 57-A | Maple | - | (4/) | - | (4/) | - | do. | - | Over |
| 60-A | White | 8.2 | .48 | 8.25 | .095 | 7,600 | Good | .16 | Ref. |
| 61-A | Lt. gray | 9.45 | .009 | 9.25 | .019 | 11,500 | do. | .21 | S |
| 71-A-c | White | 7.7 | 2.80 | (7/) | (7/) | - | Fair | .12 | Ref. |
| 75-A | do. | 5.0 | 2.76 | 4.9 | 2.60 | 4,600 | Good | .11 | Do. |
| 76-A | Brown | 13.4 | 6/7.2 | (7/) | (7/) | - | Fair | - | U |
| B | Gray cream | 9.0 | .009 | (7/) | (7/) | - | do. | .16 | S |
| C | White | 7.9 | .01 | (7/) | (7/) | - | do. | .18 | S |
| D | do. | 7.5 | .01 | (7/) | (7/) | - | do. | - | S |

1/ Total linear shrinkage, mold-to-fired size.

2/ Rating (dielectric and ceramic properties).

3/ Stuck to bedding material.

4/ Overfired

5/ No 6-inch tile made; talc needs beneficiation.

6/ Slightly blistered.

7/ Insufficient sample, no 6-inch tile made.

8/ Ref. - refractory.

TABLE 6. - Dielectric properties of 4-inch round tile using
standard cone-14 test body

| Sample No. | Dry | | | Wet | | |
|----------------------|------------------------|--------------|-----------------|------------------------|--------------|-----------------|
| | Dielectric constant | Q- factor | Loss- factor | Dielectric constant | Q- factor | Loss- factor |
| 1-A | 5.50 | 265 | 0.021 | 5.40 | 215 | 0.023 |
| I-c ₁ / | 5.80 | 230 | .026 | 5.80 | 240 | .024 |
| K-c ₁ / | 5.80 | 190 | .030 | 5.80 | 220 | .027 |
| M-c ₁ / | 5.60 | 230 | .025 | 5.60 | 230 | .025 |
| P | 5.45 | 270 | .020 | - | Porous | - |
| 6-B-c ₁ / | 5.40 | 240 | .023 | 5.40 | 240 | .023 |
| C | 5.25 | 200 | .026 | - | - | - |
| 8-C-c ₁ / | 5.40 | 200 | .027 | 5.40 | 185 | .028 |
| J | 5.85 | 40 | .140 | - | Porous | - |
| K | 5.10 | 180 | .029 | 5.10 | 170 | .030 |
| 9-C | 5.50 | 190 | .030 | 5.30 | 190 | .028 |
| C-c | 5.30 | 85 | .066 | - | Porous | - |
| D-c | 5.30 | 260 | .020 | 5.25 | 225 | .023 |
| 10-B-c | 8.85 | 64 | .140 | 8.65 | 63 | .138 |
| 15-C-c | 5.60 | 240 | .023 | 5.60 | 230 | .024 |
| E-c | 5.60 | 235 | .023 | 5.45 | 176 | .031 |
| F-c | 5.40 | 230 | .023 | 5.40 | 168 | .032 |
| 19-G | 5.60 | 240 | .023 | 5.55 | 220 | .025 |
| 20-F | 5.30 | 210 | .026 | 5.30 | 2/100 | .054 |
| 26-I-c | 5.50 | 305 | .018 | 5.55 | 220 | .025 |
| 31-B | 5.15 | 190 | .027 | - | Vesicular | - |
| 38-A | 5.50 | 160 | .035 | - | do. | - |
| 39-A-c | 5.45 | 235 | .023 | 5.50 | 220 | .024 |
| C | 5.25 | 210 | .026 | 5.50 | 2/120 | .045 |
| 43-B | 5.45 | 305 | .018 | 5.55 | 235 | .023 |
| C | 5.25 | 280 | .018 | 5.40 | 160 | .035 |
| 44-C | 5.55 | 275 | .020 | 5.55 | 285 | .019 |
| D | 5.65 | 325 | .018 | 5.60 | 210 | .026 |
| 46-A | 5.55 | 180 | .031 | - | - | - |
| 47-A | 5.50 | 250 | .023 | - | - | - |
| B | 5.40 | 215 | .026 | - | Porous | - |
| C | 5.25 | 180 | .029 | - | do. | - |
| D | 5.45 | 215 | .023 | - | do. | - |
| 48-A ² / | 5.70 | 330 | .018 | - | - | - |
| B | 5.30 | 275 | .019 | 5.50 | 2/115 | .048 |
| C ² / | 5.55 | 270 | .020 | 5.64 | 205 | .027 |
| 49-A | 5.35 | 260 | .020 | 5.45 | 190 | .031 |
| 51-A | 5.45 | 215 | .026 | - | - | - |
| A-c | 5.55 | 275 | .020 | 5.50 | 280 | .019 |
| B | 5.30 | 290 | .019 | 5.35 | 75 | .072 |
| F-c | 5.45 | 320 | .017 | 5.50 | 210 | .027 |
| 52-E | 5.70 | 235 | .024 | 5.75 | 230 | .025 |
| F | 5.75 | 245 | .023 | 5.75 | 245 | .024 |
| G | 5.70 | 255 | .023 | 5.70 | 235 | .024 |
| H | 5.70 | 235 | .024 | 5.75 | 215 | .025 |

Note: See footnotes on p. 52.

TABLE 6. - Dielectric properties of 4-inch round tile using standard cone-14 test body (Cont'd.)

| Sample No. | Dry | | | Wet | | |
|------------|---------------------|----------|-------------|---------------------|-----------|-------------|
| | Dielectric constant | Q-factor | Loss-factor | Dielectric constant | Q-factor | Loss-factor |
| 53-A | 4.75 | 130 | 0.037 | - | Vesicular | - |
| A-c | 5.15 | 210 | .024 | - | Porous | - |
| 54-A | 5.55 | 205 | .027 | 5.55 | 94 | 0.059 |
| B | 5.50 | 280 | .019 | 5.60 | 210 | .026 |
| 55-A | 5.50 | 280 | .020 | 5.55 | 60 | .070 |
| 56-A | 5.20 | 215 | .024 | - | Porous | - |
| 60-A | 5.40 | 215 | .026 | 5.80 | 45 | .325 |
| 61-A | 5.45 | 325 | .017 | 5.35 | 280 | .019 |
| 71-A-c | 5.40 | 295 | .018 | - | Porous | - |
| 75-A | 5.10 | 165 | .028 | - | do. | - |
| 76-B | 5.45 | 295 | .019 | 5.60 | 200 | .028 |
| C | 5.30 | 310 | .017 | 5.40 | 210 | .026 |
| D | 5.50 | 310 | .017 | 5.55 | 230 | .024 |

1/ Measurements by the American Lava Corporation.

2/ Fired to cone 13.

3/ Slightly porous structure.

TABLE 7. - Dielectric properties of 6-inch square by 1/4-inch thick tile using standard cone-14 test body measured by the U. S. Naval Research Laboratory

| Sample No. | Q-factor | Loss-factor | Dielectric constant |
|------------|----------|-------------|---------------------|
| 1-A | 315 | 0.017 | 5.25 |
| I-c | 275 | .020 | 5.60 |
| K-c | 245 | .023 | 5.60 |
| M-c | 605 | .0087 | 5.35 |
| P | 410 | .013 | 5.40 |
| 6-B-c | 125 | .041 | 5.20 |
| C | 310 | .016 | 5.05 |
| 8-C-c | 55 | .091 | 5.00 |
| E | 80 | .056 | 4.50 |
| 9-C | 420 | .012 | 5.30 |
| C-c | 50 | .21 | 5.35 |
| D | 350 | .015 | 5.20 |
| 15-C-c | 295 | .018 | 5.40 |
| E-c | 315 | .018 | 5.30 |
| F-c | 310 | .017 | 5.25 |
| 19-G | 320 | .017 | 5.50 |
| 20-D-c | 195 | .025 | 4.90 |
| F | 440 | .013 | 5.50 |
| 26-I-c | 355 | .016 | 5.55 |
| 39-A-c | 285 | .019 | 5.50 |
| C | 435 | .011 | 5.10 |
| 43-B | 430 | .012 | 5.45 |
| C | 400 | .013 | 5.40 |

TABLE 7. - Dielectric properties of 6-inch square by 1/4-inch thick tile using standard cone-14 test body measured by the U. S. Naval Research Laboratory (Cont'd.)

| Sample No. | Q-factor | Loss-factor | Dielectric constant |
|--------------------|----------|-------------|---------------------|
| 44-C | 395 | 0.014 | 5.55 |
| D | 445 | .012 | 5.60 |
| 46-A | 270 | .019 | 5.25 |
| 47-A | 295 | .019 | 5.50 |
| 48-A ^{1/} | 615 | .009 | 5.75 |
| B | 320 | .017 | 5.45 |
| C ^{1/} | 395 | .014 | 5.35 |
| 51-A | 470 | .012 | 5.35 |
| A-c | 330 | .016 | 5.50 |
| F | 495 | .011 | 5.45 |
| 52-E | 340 | .017 | 5.60 |
| F | 355 | .016 | 5.65 |
| G | 360 | .016 | 5.60 |
| H | 325 | .018 | 5.65 |
| 54-A | 355 | .017 | 5.55 |
| 60-A | 355 | .016 | 5.40 |
| 61-A | 440 | .013 | 5.55 |
| 75-A | 255 | .020 | 5.00 |

^{1/} Fired to cone 13.

Talc samples that were satisfactory in the cone-14 body were also suitable substitutes for Sierra talc in the cone-12 mixture, with few exceptions. Talc 8-C-c which was not vitrified in the cone-14 body, was satisfactory for the low-temperature body. Samples 39-C, satisfactory in the high-temperature body, gave porous bodies in the cone-12 series. These results indicate that a cone-14 test body is satisfactory for comparing the firing behavior of different talcs. The few samples that behaved differently in the two mixtures indicate that substitution into the manufacturer's own production body is the only sure test for a new talc. The average Q-factor of the cone-12 body was approximately double that for the cone-14 body.

TABLE 8. - Properties of 4-inch round tile using standard cone-12 test body

| Sample No. | Absorption, percent | Shrinkage, percent | Dielectric constant | Q-factor | Loss- factor |
|------------|------------------------|-----------------------|------------------------|----------|-----------------|
| 1-A | 0.068 | 11.05 | 6.10 | 630 | 0.010 |
| P | .219 | 9.20 | 5.65 | 535 | .011 |
| 8-C-c | .036 | 9.70 | 5.85 | 595 | .010 |
| J | 3.20 | 15.3 | 5.3 | 25 | .212 |
| K | .036 | 11.2 | 6.10 | 320 | .019 |
| 15-E | .039 | 12.5 | 6.20 | 570 | .011 |
| F | .049 | 13.15 | 6.20 | 700 | .009 |
| 20-D-c | 5.60 | 7.40 | 5.15 | 410 | .016 |
| 26-I-c | .030 | 12.30 | 6.20 | 560 | .011 |
| 38-C&D | - | overfired | - | - | - |
| 39-A-c | .045 | 12.40 | 6.15 | 490 | .012 |
| C | .133 | 11.4 | 5.85 | 1/900 | .007 |
| 43-B | .058 | 12.45 | 5.70 | 560 | .010 |
| C | .042 | 11.80 | 5.90 | 350 | .018 |
| 46-A | .014 | 11.20 | 6.20 | 785 | .0084 |
| 48-B | .090 | 10.7 | 6.10 | 470 | .013 |
| C | - | overfired | - | - | - |
| 57-A | .22 | 9.7 | 5.65 | 325 | .019 |
| 75-A | 8.40 | 5.9 | 5.15 | 645 | .009 |

1/ 1 tile only.

Results

Satisfactory Ceramic Properties

The talc samples listed in table 9 were satisfactory substitutes for Sierra talc within the assigned limitations of ceramic and dielectric properties.

Fourteen out of 31 acceptable talcs came from California. One New Mexico sample and 5 from Montana were satisfactory as mined. The Alabama talc required beneficiation by flotation and also had a high shrinkage. Talc 15-F-c was similar to 15-E-c but was acid-leached to reduce the iron oxide content. This procedure improved the color but had no definite effect on the other properties. Two selected New York talc samples appeared to be suitable as mined, but the sampling of 51-B is open to question. Two other New York talcs from the same district were particularly satisfactory after beneficiation.

1. Inferior Dielectric Properties. - Several talcs (table 10) were suitable as far as ceramic properties are concerned but had dielectric properties inferior to those of the standard Sierra talc.

TABLE 9. - Satisfactory substitutes for Sierra talc on basis of ceramic and dielectric properties

| Sample No. | Source | Sample No. | Source |
|------------|--------------------------|------------|---------------------------|
| 1-I-c | California | 48-B | California |
| M-c | do. | 49-A | Do. |
| P | do. | 51-A-c | New York |
| 9-D-c | Virginia | B | Do. ^{3/} |
| 15-C-c | Alabama | F-c | Do. |
| E | do. | 52-E | Montana |
| F-c | do. | F | Do. |
| 19-G | Nevada | G | Do. |
| 20-F | New York ^{1/} | H | Do. |
| 26-I-c | California | 54-B | New Mexico |
| 39-A-c | Montana | 55-A | Frozen cosmetic inventory |
| 43-B | California | | |
| C | do. | 61-A | Nevada |
| 44-C | Nevada | 76-B | California ^{4/} |
| D | do. | C | Do. ^{4/} |
| 47-A | California ^{2/} | D | Do. ^{4/} |

^{1/} Slightly higher temperature necessary.

^{2/} High-lime talc.

^{3/} Qualified recommendation, doubtful sampling.

^{4/} Qualified recommendation, insufficient sample.

TABLE 10. - Talc samples vitrified at cone 14 but with inferior dielectric properties

| Sample No. | Source |
|-------------|------------------------|
| 1-K-c | California |
| 6-C | North Carolina |
| 8-K | New York |
| 9-C | Virginia |
| 39-C | Montana |
| 46-A | California |
| 51-A | New York ^{1/} |
| 54-A | Nevada |

^{1/} Doubtful sampling.

All of these could be used as blends with other talcs or could be used alone to make a body that might have slightly lower Q-factor but still be within the same American Standards Association loss-factor grade as a body of the same composition using Sierra talc. The Virginia talc, satisfactory as mined, came from a small deposit. New York talc 51-A was definitely satisfactory after flotation. The iron oxide content of the North Carolina talc was rather high, but it should be useful in large percentages as a blend material.

2. Shrinkage. - The accepted shrinkage range (6 to 10 percent linear shrinkage) is rather wide. Several samples had shrinkages equal to that of the Sierra within the ± 1 percent tolerance specified by the American Standards Association war standard for steatite insulators. Among these are the samples given in table 11.

Since the manufacturer of steatite ceramics has dies cut for a body of definite shrinkage, it might be necessary to blend two or more of the other acceptable talcs to secure the desired value. The Alabama talc had the highest shrinkage of any of the acceptable talcs, and unless it were used for a new body or in new shapes where dies had not yet been cut, it probably would be a minor rather than a major blend constituent.

TABLE 11. - Talc samples with linear shrinkage approximately equal to that of Sierra talc

| Sample No. | Source |
|------------|----------------|
| 6-C | North Carolina |
| 9-C | Virginia |
| 19-G | Nevada |
| 39-C | Montana |
| 43-C | California |
| 46-A | Do. |
| 47-A | Do. |
| 48-B | Do. |
| 49-A | Do. |
| 76-B | Do. |
| C | Do. |

Unsatisfactory Ceramic Properties

1. Refractory Talcs. - Another group of samples was not acceptable as substitutes for Sierra talc, since their vitrification characteristics differed from those of the standard. Table 12 lists talcs that were more refractory than the standard Sierra talc but might be used in blends, fired at higher temperatures, or employed with increased amounts of flux.

TABLE 12. - Talc samples not vitrified at cone 14

| Sample No. | Source |
|--------------|----------------|
| 6-B-c | North Carolina |
| 8-C-c | New York |
| E-c | Do. |
| J | Do. |
| 9-C-c | Virginia |
| 20-D-c | New York |
| 47-B | French talc |
| C | Indian talc |
| 53-A-c | North Carolina |
| 56-A | Italian talc |
| 60-A | Nevada |
| 61-A-c | Canada |
| 75-A | India |

The New York State samples had large amounts of lime that tended to increase the abrasiveness of these talcs. Any refractory talc mentioned above may be used as a blend material with the more fusible talcs mentioned below and give bodies firing at cone 14. The use of the refractory New York talcs is limited mainly by their abrasiveness.

2. Low-Temperature Talcs. - The logical blend materials to be used with the above are talcs that vitrify at a lower temperature than the standard, such as those shown in table 13.

TABLE 13. - Talc samples overfired at cone 14

| Sample No. | Source |
|------------|------------|
| 20-E | New York |
| 31-B | California |
| 38-A | Do. |
| C&D | Do. |
| 48-A | Do. |
| C | Do. |

If these talcs are to be used alone they can be fired at a lower temperature or else some of the fluxes may be removed from the steatite mixture. Most of these had the same high lime impurite as the refractory talcs, and the abrasion problem would be important again if any such blends are used. In any event, small quantities of either the refractory or fusible talcs may be incorporated into a body using a softer talc without harmful effects. This procedure is already practiced by some manufacturers of high-frequency insulators.

Several of the talcs whose ceramic properties were investigated cannot be used even as blend materials so far as the results of the present investigation are concerned. These are the following:

TABLE 14. - Talc samples not suitable to be used alone in steatite mixtures

| Sample No. | Source |
|--------------|----------------|
| 10-B-c | Maryland |
| 47-D | Calcined talc |
| 50-A | Synthetic talc |
| 53-A | North Carolina |
| 57-A | Canada |
| 76-A | California |

Samples 47-D and 50-A were both abrasive and had very high shrinkage. The others had too much Fe_2O_3 even after beneficiation.

Uniformity of Talc

Items 4 and 6 of the manufacturer's specification for talc, quoted on page 7 present the questions of deviation between successive shipments of talc and available supply. Any change in the properties of the talc will cause some disturbance in normal plant operation. Obviously, then, no manufacturer desires to use a talc of which there is not an assuredly adequate supply for his needs. The abrupt vitrification of bodies containing large quantities of talc differs markedly from the gradual vitrification of most ceramic mixtures and causes a short firing range. Small variations from shipment to shipment can be harmful enough to cause rejection of an otherwise satisfactory talc.

LIMITATIONS OF SURVEY

The authors are aware that the data presented in this report do not carry the program of talc testing through to the degree of completion desired. However, easing of the stringency in the talc situation early in 1943 caused the investigation to be recessed in order that attention might be given to more critical problems. Completion of the survey would necessitate further work.

The ceramic tests have disclosed several talcs that can be substituted for the Sierra talc. However, the eastern talcs are in general either too refractory or have high linear shrinkage. If the talc situation should again become critical, it would be advantageous to select the most suitable of these eastern talcs and experiment as follows:

1. Blend with other talcs to show relation of composition versus shrinkage and other properties. In this way it should be possible to develop a blend either of several eastern talcs or of eastern and western talcs that can be substituted directly for the Sierra talc without any changes in the manufacturing procedure.

2. Change firing temperature, if necessary, to obtain correct vitrification temperature for the underfired talcs.

3. Develop new body compositions containing increased fluxes for the refractory talcs.

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REPORT OF INVESTIGATIONS

ELECTROLYSIS OF MAGNESIUM INTO LIQUID CATHODES FROM MgO-CARBON SUSPENSIONS IN MOLTEN CHLORIDES



BY

BURKE CARTWRIGHT, LLOYD R. MICHELS, AND S. F. RAVITZ



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REPORT OF INVESTIGATIONS

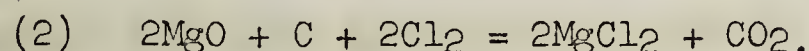
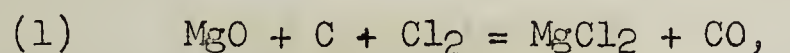
UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ELECTROLYSIS OF MAGNESIUM INTO LIQUID CATHODES FROM MgO-CARBON
SUSPENSIONS IN MOLTEN CHLORIDES^{1/}

By Burke Cartwright,^{2/} Lloyd R. Michels,^{3/}
and S. F. Ravitz^{4/}

INTRODUCTION

Frequent attempts have been made in the electrolysis of molten magnesium chloride to regenerate the electrolyte by allowing the chlorine generated at the anode to react with magnesium oxide and carbon within the melt according to the following reactions:



The principal advantages of such a procedure are that (1) the direct source of magnesium is magnesium oxide rather than the more expensive dehydrated magnesium chloride and (2) it is not necessary to handle or dispose of large quantities of chlorine or hydrogen chloride.

Gratzell^{5/} proposed the use of an MgO-carbon feed in a more or less compact form in the anode compartment of the cell. In a patent issued to Magall Aktiengesellschaft,^{6/} a compact mixture of MgO and carbon is used as the anode itself. Kato^{7/} and Backer^{8/} add the feed in finely divided

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3805."

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4/ Metallurgist, Intermountain Experiment Station, Bureau of Mines, Salt Lake City, Utah.

5/ Gratzell, R., German patent 26,962, 1883.

6/ Magall Aktiengesellschaft, Electrolytic Production of Magnesium and Alkaline Earth Metals: British Patent 452,269, Aug. 19, 1936.

7/ Kato, Yogoro, Magnesium: British Patent 447,600, May 21, 1936, (divided on and addition to British Patent 447,083).

8/ Backer, C. B., Norwegian Patent 34,247, 1920.

form to the surface of the anode compartment. The Bureau of Mines^{9/} recently made a pilot-plant investigation of the electrolysis of suspensions of MgO and carbon from chloride melts, in which it was found that although current efficiencies of 60 to 70 percent were obtainable, the formation of sludges containing MgO, carbon, and magnesium seriously interfered with the operation of the cell.

The use of a molten-metal cathode in the direct electrolysis of MgO-carbon suspensions appeared to offer possibilities of decreasing the difficulties caused by sludge formation, of simplifying cell design, and of increasing the current efficiency and was therefore investigated by the Bureau of Mines. The use of lead as a liquid cathode for the electrolysis of magnesium chloride, together with an electrolytic method for separating magnesium from the resulting alloy, has been patented by Ashcroft^{10/} and described by Allen.^{11/} The use of molten aluminum as a cathode has been patented by von Kugelgen and Seward^{12/} and has been investigated in considerable detail by Weiner.^{13/}

EQUIPMENT AND PROCEDURE

Description of Cell

The cell used in this investigation consisted essentially of an alundum crucible placed in a cast-iron pot, as shown in figure 1. A replaceable gastight transite cover, to which a 3-inch graphite anode was attached, was provided so that quantitative measurements could be made of the gas evolved. The MgO-carbon feed was added to the cell through the gas outlet, which was a 2-inch transite tube extending through the cover. Electrical contact to the molten-lead cathode was made by means of an insulated iron rod extending through the chloride melt. Preliminary tests were made with a cell lined with a bottomless alundum cylinder, the current being conducted through the iron pot to the molten lead, which rested directly on the bottom of the pot. Because the alundum tended to become soaked with the chloride melt, however, part of the current short-circuited through the alundum, and some magnesium was deposited at the walls of the pot rather than in the lead, causing low cathode-current efficiencies. This difficulty was overcome by using the alundum crucible instead of a cylinder and using the insulated iron rod for

-
- ^{9/} Lloyd, R. R., Stoddard, C. K., Mattingly, K. L., Leidigh, E. T., and Knickerbocker, R. G., Pilot-Plant Production of Electrolytic Magnesium from Magnesia: To be published by Am. Inst. Min. and Met. Eng.
- ^{10/} Ashcroft, E. A. Electrolytic Apparatus for Producing Magnesium and Its Alloys and Chlorine from Anhydrous Magnesium Chloride: U. S. Patent 1,359,653, Nov. 23, 1920; British Patent 215,872, 1923.
- ^{11/} Allen, S. T., Production of Metallic Magnesium: Chem. and Met. Eng., vol. 26, 1922, pp. 987-988.
- ^{12/} von Kugelgen, Franz, and Seward, George O., Electrolytic Production of Magnesium: U. S. Patent 935,796, Oct. 5, 1909.
- ^{13/} Weiner, R., (Direct Preparation of Magnesium-Aluminum Alloys from Fused Electrolyte): Ztschr. Elektrochem., vol. 38, 1932, pp. 232-240.

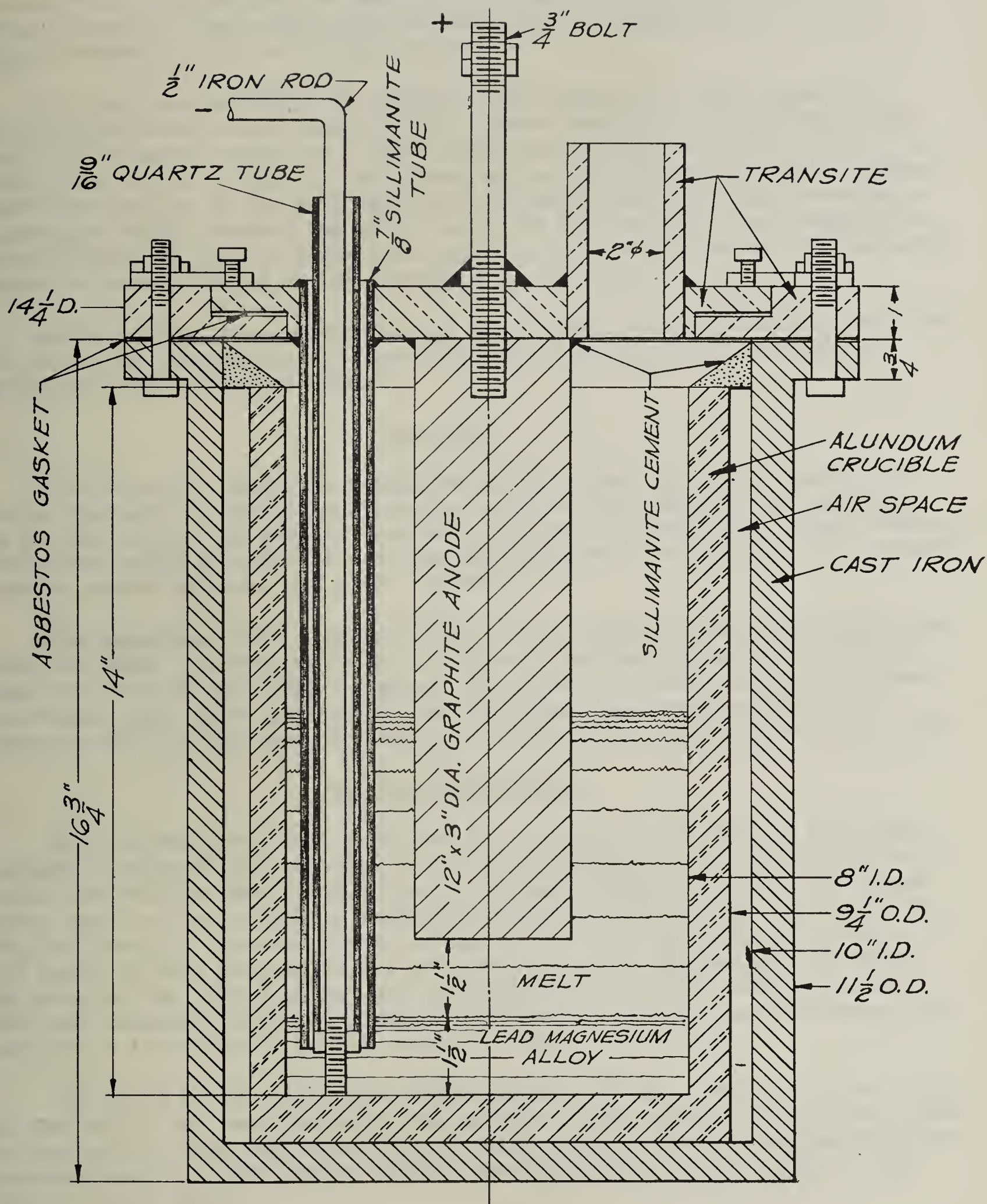
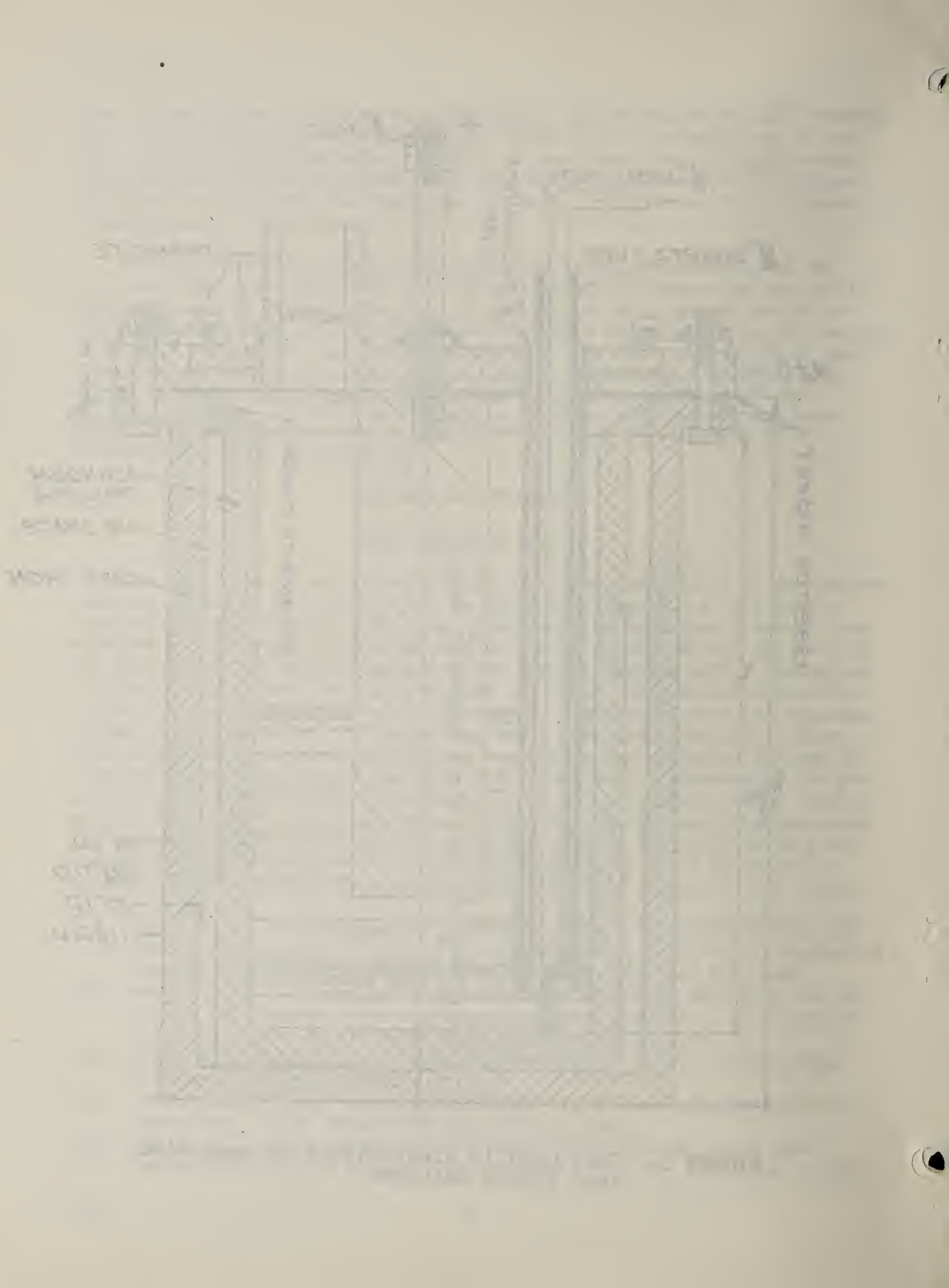


FIGURE 1.- Cell used in electrolysis of magnesium into liquid cathodes.



the electrical connection, so that the iron pot was not part of the electrical circuit. The design could be simplified in large cells by using a bottom connection for the cathode current.

The cell was heated by an electric pot furnace of 4.5-kw. capacity. The nichrome resistance element of the furnace was covered with a thin coating of sillimanite cement to prevent corrosion. A chromel-alumel thermocouple (not shown in fig. 1) in a fused-silica well extending about 3 inches below the surface of the melt indicated the melt temperature and actuated a controller which governed the power supply to the furnace. The temperature was difficult to control closely at high current density because of the large amount of heat produced by the electrolyzing current.

Anode consumption was appreciable at the high current densities employed. The anode was therefore replaced after about 6 hours of cell operation, except in long continuous runs.

Cell Feed

The technical anhydrous magnesium chloride used in all the tests was rather powdery and dusted badly in the cell until it melted. It contained 97 percent $MgCl_2$, 1.5 percent free MgO , and small amounts of iron and moisture. Each fresh batch of chloride melt was electrolyzed 2 to 3 hours before being used to remove moisture and other impurities.

The magnesium oxide used was Baker's c.p. "dense" grade, which was finer than 200-mesh. It behaved better in the melt and proved easier to handle than the "medium" or "light" grades. The carbon was added as minus 200-mesh petroleum coke. Both the MgO and the petroleum coke were calcined for 8 hours at $700^{\circ}C$. and were reheated for 1 hour at 400° just before being used.

Experimental Methods

Most of the tests were conducted for 3 hours at 250 amperes (cathode current density of 5.0 amperes per square inch) with a lead cathode and with magnesium chloride melts containing 10 percent MgO and 1 percent petroleum coke, based on the weight of magnesium chloride; MgO and coke were added to the melt every 30 minutes at the estimated rate of depletion. In each test, the depth of melt was maintained between 5-1/2 and 6 inches and the depth of alloy at the bottom of the cell at approximately 1-1/2 inches, so that the cell contained about 16 pounds of melt and (depending upon the magnesium content of the alloy) 2.3 to 28 pounds of lead.

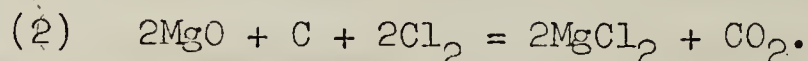
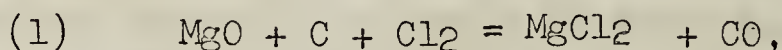
The level of the alloy rose approximately 1/4 inch during a 3-hour test; at the end of the test the alloy was agitated with helium, and part of it was ladled out to bring the level back to 1-1/2 inches. The spacing between the graphite anode and the molten cathode was adjusted to 1-1/2 inches at the start of each test.

The rate of evolution of gas from the cell was measured by displacement of water, an intermediate flask of air being used to prevent contact of the gas with the water. The composition of the gas was determined by treating a sample of known volume with sodium arsenite solution and analyzing the residual gas for CO_2 , CO , O_2 , and inert gas. The free chlorine was calculated from the amount of arsenite oxidized. It was assumed that the difference between the free chlorine and the total chlorine in the solution was due to hydrolysis of phosgene to CO_2 and HCl , tests on known mixtures of CO_2 , CO , and Cl_2 having shown that considerable phosgene was formed. Since much of the CO_2 was dissolved by the sodium arsenite solution, the volume of CO_2 was found by the difference between the volume of the sample and the volume of other gases accounted for. A few samples were analyzed more completely and found to contain a total of less than 0.3 percent of hydrogen and hydrocarbon. The remainder of the inert gas was presumably nitrogen. The composition of the gas (the "corrected gas analysis") was expressed in terms of CO_2 , CO , and Cl_2 , the phosgene being calculated to the equivalent CO and Cl_2 .

The anode current efficiencies were determined from the rate of evolution of gas exclusive of oxygen and inert gas, the corresponding corrected gas analysis, and the current during the measurement of the gas rate. The efficiencies determined are only indicative, for they are not only subject to uncertainties due to the presence of nitrogen in the gas, but there is also a possibility that the gas might contain small quantities of hydrogen chloride, despite the precautions taken to eliminate moisture from the charge. Such hydrogen chloride would be determined as phosgene and calculated as chlorine. However, the anode efficiencies usually agreed fairly well with the cathode efficiencies and were often close to 100 percent.

The cathode-current efficiencies were calculated from the time, average current, and gain in magnesium content of the alloy during the test. The precision of the method of analysis,^{14/} which was checked against alloys of known magnesium content, was such that normal analytical errors would cause an error of not more than 3 percent in the efficiency. Although the magnesium showed a slight tendency to react with the cell materials, the error from this source was probably small in the 3-hour runs, since the magnesium content of the alloy decreased by only a few tenths of 1 percent when the molten bath was allowed to stand overnight.

The percentage of chlorine reacting was based on the reactions:



^{14/} The lead-magnesium alloy is dissolved in nitric acid, the lead is precipitated with hydrogen sulfide and filtered off, and the excess hydrogen sulfide is boiled out. The solution is then neutralized to methyl red, an excess of standard sodium hydroxide is added, the magnesium hydroxide precipitate is filtered off, and an aliquot part of the filtrate is back-titrated with standard acid to the same methyl red end point.

It was calculated from the corrected gas analysis by use of the expression $\frac{100 \sqrt{2(\text{CO}_2) + (\text{CO})}}{(\text{Cl}_2) + (\text{CO}_2) + (\text{CO})}$, since each mol of CO_2 is equivalent to 2 mols of chlorine and each mol of CO is equivalent to 1 mol of chlorine.

The current and voltage, which were recorded at about 20-minute intervals during each test, were usually within 2 percent of the average current and voltage, respectively, and seldom varied from the averages by more than 4 percent.

The decomposition voltage was determined at the end of each hour by varying the current in five successive steps of 20 to 50 amperes, measuring the corresponding voltages, and extrapolating the current-voltage curve to zero current; the points fell rather smoothly on a straight line so that the uncertainty in the extrapolation was less than 0.1 volt. The back e.m.f. was determined at approximately the same time by interrupting the cell current suddenly and noting the voltmeter reading, which usually remained constant for 1 to 3 minutes. The cell resistance, as determined from the slope of the current-voltage curve, averaged about 0.03 ohm. It showed no definite correlation with any of the operating variables, but fluctuated from test to test by as much as 0.01 ohm from the average, owing largely to small variations in anode-cathode spacing, anode erosion, and sludge formation over the alloy.

EXPERIMENTAL RESULTS

Tests with Lead Cathodes

Effect of MgO and Carbon on Electrolysis of MgCl_2

Table 1 shows the results of 3-hour tests on MgCl_2 alone, MgCl_2 with 10 percent MgO, and MgCl_2 with 10 percent MgO and 1 percent petroleum coke. Two different MgCl_2 melts were used, tests 11, 13, and 14 being made with one and tests 15, 16, and 17 with the other.

High current efficiencies were obtained with the first melt and fairly high efficiencies with the second. It will be noted in subsequent tables that anode and cathode efficiencies approaching 100 percent were obtained frequently with MgCl_2 melts containing 10 percent MgO and 1 percent carbon.

In the electrolysis of MgCl_2 alone, the gas contained an appreciable quantity of CO_2 and CO, owing presumably to reaction of chlorine with the graphite anode and small amounts of MgO (and possibly moisture) in the salt. About half the chlorine reacted when 10 percent MgO was added to the melt, and nearly all the chlorine reacted when 10 percent MgO and 1 percent petroleum coke were present.

TABLE 1. - Effect of MgO and carbon on electrolysis of $MgCl_2$ with lead cathodeMelt: $MgCl_2$

Cathode current density: 5.0 amp. per sq. in.

Time: 3.0 hours

| Test No. | 11 | 15 | 13 | 16 | 14 | 17 |
|-----------------------------------|-------|-------|------|-------|------|------|
| Added, percent: | | | | | | |
| MgO | 0 | 0 | 10 | 10 | 10 | 10 |
| Petroleum coke | 0 | 0 | 0 | 0 | 1 | 1 |
| Temperature, degrees C. (average) | 815 | 791 | 840 | 837 | 830 | 823 |
| Current, amp. (average)..... | 252 | 249 | 252 | 249 | 249 | 252 |
| Voltage (average) | 9.4 | 8.9 | 9.1 | 9.1 | 9.2 | 9.2 |
| Mg content of alloy, percent: | | | | | | |
| Initial | .0 | .20 | 4.88 | 2.50 | 7.05 | 4.58 |
| Final | 2.67 | 2.50 | 7.13 | 4.58 | 9.34 | 6.72 |
| Current efficiency, percent: | | | | | | |
| Anode | 101 | 94 | 1/ | 89 | 1/ | 85 |
| Cathode | 101 | 89 | 93 | 84 | 100 | 88 |
| Chlorine reacted, percent | 23 | 23 | 66 | 41 | 97 | 95 |
| Gas rate, ml. per min., S.T.P. .. | 1,675 | 1,495 | 1/ | 1,300 | 1/ | 985 |
| Analysis of gas, percent: | | | | | | |
| Uncorrected: | | | | | | |
| Cl ₂ | 80.6 | 81.7 | 46.8 | 67.7 | 0.0 | 1.0 |
| COCl ₂ | 3.4 | 1.3 | .3 | 1.0 | 5.1 | 6.7 |
| CO ₂ | 11.0 | 11.7 | 45.2 | 22.6 | 80.0 | 69.1 |
| CO | .3 | .2 | 1.4 | 1.2 | 8.5 | 8.8 |
| O ₂ | 1.1 | 1.2 | 1.5 | 1.5 | .3 | .5 |
| Inert | 3.6 | 3.9 | 4.8 | 6.0 | 7.1 | 13.9 |
| Corrected: | | | | | | |
| Cl ₂ | 85.2 | 86.3 | 50.1 | 73.5 | 5.3 | 8.3 |
| CO ₂ | 11.1 | 12.2 | 48.1 | 24.2 | 80.8 | 74.9 |
| CO | 3.7 | 1.5 | 1.8 | 2.3 | 13.9 | 16.8 |
| Decomposition voltage: | | | | | | |
| 1 hour | 1.8 | 2.0 | 2.2 | 1.8 | 2.2 | 2.1 |
| 2 hours | 2.4 | 2.1 | 2.3 | 2.1 | 2.2 | 2.2 |
| 3 hours | 1.9 | 2.3 | 2.3 | 2.3 | 1.9 | 2.4 |
| Back e.m.f.: | | | | | | |
| 1 hour | 2.0 | 1.8 | 1.9 | 1.8 | 2.0 | 1.8 |
| 2 hours | 2.3 | 2.1 | 2.1 | 2.1 | 2.1 | 2.0 |
| 3 hours | 2.3 | 2.2 | 2.3 | 2.2 | 1.7 | 2.1 |

1/ Gas rate could not be determined because of leak in cover.

The decomposition voltages and back e.m.f.'s are intermediate between the theoretical reaction potential^{15/} for reactions 1 and 2 (approximately 1.5 volts at 800° C.) and that for the decomposition of magnesium chloride (approximately 2.5 volts).

^{15/} Kelloy, K. K., Energy Requirements and Equilibria in the Dehydration, Hydrolysis, and Decomposition of Magnesium Chloride: Bureau of Mines Tech. Paper 676. In press.

Effect of Current Density

The results of tests at various cathode-current densities are summarized in tables 2 and 3. The anode-current densities are uncertain; if the cross-sectional area (7.07 sq. in.) of the graphite electrode is assumed to be the effective anode area, the anode-current densities are approximately seven times the cathode-current densities. The data in table 2 are for the individual 3-hour tests, while those in table 3 are for a series of successive half-hour tests. The over-all cathode-current efficiency for the tests in table 3, based on the composition of the alloy at the beginning and end of the series, was 85 percent.

TABLE 2 - Effect of current density on cathode efficiencyMelt: MgCl_2 with 10 percent MgO and 1 percent carbon

Time: 3 to 4.7 hours

| Test No. | 17 | 19 | 22 | 18 | 21 |
|--|------|------|------|------|------|
| Cathode-current density, | | | | | |
| amp. per sq. in. | 5.0 | 4.0 | 3.0 | 2.6 | 1.9 |
| Temperature, degrees C. (average) | 823 | 826 | 815 | 794 | 800 |
| Current, amp. (average) | 252 | 199 | 149 | 131 | 97.8 |
| Voltage (average) | 9.2 | 9.5 | 8.2 | 6.8 | 6.0 |
| Mg content of alloy: | | | | | |
| Initial | 4.58 | 1.54 | 5.29 | .25 | 4.17 |
| Final | 6.72 | 3.67 | 7.04 | 2.04 | 5.20 |
| Cathode-current efficiency, percent | 88 | 84 | 92 | 84 | 84 |
| Chlorine reacted, percent | 95 | 98 | 98 | 98 | 97 |
| Decomposition voltage (average) | 2.2 | 2.0 | 2.1 | 2.0 | 1.8 |
| Back e.m.f. (average) | 1.9 | 1.9 | 1.7 | 1.8 | 1.6 |

It is doubtful whether the drop in anode efficiency and the changes in the corrected gas analysis with decreasing current density are due to any inherent effect of current density. The sources of uncertainty in the anode efficiencies discussed previously would, in general, have a greater effect at low current density (that is, at low gas rates) than at high and could give rise to trends such as those observed. For example, the evolution of hydrogen chloride at a very low rate would have little effect on the corrected gas analysis at high current density but would cause the corrected CO and Cl_2 contents to increase as the current density decreased.

Effect of Temperature

The results of tests made at constant current density and various temperatures are given in tables 4 and 5; table 4 shows the data for individual 3-hour tests, and table 5 shows the data for a series of successive half-hour tests.

TABLE 3. - Effect of current density on anode efficiency

Melt: MgCl_2 with 10 percent MgO and 1 percent carbon
 Time: 30 minutes

| Test No. | 20A | 20B | 20C | 20D | 20E | 20F |
|---|------|------|------|------|------|------|
| Cathode-current density, amp. per sq. in. | 6.0 | 5.0 | 4.0 | 3.0 | 2.0 | 1.0 |
| Temperature, degrees C. | 800 | 805 | 800 | 795 | 795 | 780 |
| Current, amp. | 300 | 249 | 201 | 153 | 102 | 53 |
| Voltage | 11.5 | 9.9 | 8.7 | 7.4 | 5.6 | 3.9 |
| Anode-current eff., percent | 100 | 97 | 102 | 94 | 85 | 85 |
| Chlorine reacted, percent | 98.2 | 98.7 | 97.0 | 96.5 | 95.9 | 93.9 |
| Gas rate, ml. per min., S.T.P. | 1210 | 975 | 875 | 665 | 465 | 265 |
| Analysis of gas, percent: | | | | | | |
| Uncorrected: | | | | | | |
| Cl_2 | .15 | .0 | .0 | .0 | .0 | .0 |
| COCl_2 | 3.1 | 2.4 | 5.1 | 5.6 | 5.7 | 8.0 |
| CO_2 | 83.0 | 82.5 | 76.6 | 70.6 | 60.2 | 55.7 |
| CO | 5.35 | 7.3 | 8.8 | 8.1 | 7.1 | 4.8 |
| O_2 | .3 | .3 | .3 | .3 | .5 | .5 |
| Inert | 8.1 | 7.5 | 9.2 | 15.4 | 26.5 | 31.0 |
| Corrected: | | | | | | |
| Cl_2 | 3.4 | 2.5 | 5.4 | 6.2 | 7.3 | 10.5 |
| CO_2 | 87.7 | 87.2 | 80.1 | 78.6 | 76.4 | 72.7 |
| CO | 8.9 | 10.3 | 14.5 | 15.2 | 16.3 | 16.8 |

TABLE 4. - Effect of temperature, 3-hour tests

Melt: MgCl_2 with 10 percent MgO and 1 percent carbon
 Cathode-current density: 5 amp. per sq. in.

| Test No. | 27 | 24 | 25 | 26 |
|--------------------------------------|------|------|------|------|
| Temperature, degrees C. | 805 | 840 | 890 | 905 |
| Current, amp. (average) | 248 | 245 | 250 | 251 |
| Voltage (average) | 10.7 | 11.1 | 9.8 | 8.8 |
| Mg content of alloy: .. | | | | |
| Initial | 6.46 | 5.43 | .90 | 2.24 |
| Final | 9.44 | 9.01 | 4.20 | 5.09 |
| Current efficiency, percent: | | | | |
| Anode | 99 | 101 | 99 | 107 |
| Cathode | 89 | 93 | 1/ | 94 |
| Chlorine reacting, percent | 99 | 98 | 98 | 99 |
| Decomposition voltage (average) | 2.2 | 2.1 | 1.7 | 1.9 |
| Back e.m.f. (average) | 2.0 | 1.9 | 1.6 | 1.7 |

1/ Some of alloy lost through small crack in crucible.

The data show no significant effect of temperature on anode or cathode efficiency or on percentage of chlorine reacting. The results in table 5, however, show a steady increase in the ratio of CO to CO_2 as the temperature rises, which may be due to increase in the rate of the reaction $\text{C} + \text{CO}_2 = 2\text{CO}$.

TABLE 5. - Effect of temperature, successive 30-minute testsMelt: MgCl_2 with 10 percent MgO and 1 percent carbon.

Cathode-current density: 5 amp. per sq. in.

| Test No. | 23C | 23D | 23E | 23A | 23B |
|---|------|------|------|------|-------|
| Temperature, degrees C. | 750 | 800 | 855 | 855 | 900 |
| Current, amp. | 246 | 250 | 249 | 251 | 254 |
| Voltage | 4.9 | 5.0 | 5.0 | 5.0 | 5.1 |
| Anode current eff., percent | 95 | 96 | 96 | 95 | 96 |
| Chlorine reacted, percent | 98.7 | 98.3 | 98.3 | 97.4 | 98.0 |
| Gas rate, ml. per min., S.T.P. | 970 | 985 | 985 | 995 | 1,000 |
| Analysis of gas, percent: | | | | | |
| Uncorrected: | | | | | |
| Cl_2 | .1 | .0 | .1 | .3 | .1 |
| COCl_2 | 2.1 | 3.0 | 2.9 | 4.2 | 3.5 |
| CO_2 | 80.1 | 80.1 | 80.0 | 77.9 | 79.0 |
| CO | 7.7 | 9.5 | 9.7 | 8.7 | 10.6 |
| O_2 | .2 | .3 | .3 | .5 | .2 |
| Inert | 9.8 | 7.1 | 7.0 | 8.4 | 6.6 |
| Corrected: | | | | | |
| Cl_2 | 2.4 | 3.1 | 3.1 | 4.8 | 3.7 |
| CO_2 | 84.0 | 83.9 | 83.8 | 81.7 | 81.7 |
| CO | 10.6 | 13.0 | 13.1 | 13.5 | 14.6 |
| Ratio, $\text{CO} : \text{CO}_2$ (corr.) | .122 | .155 | .156 | .165 | .179 |

Effect of Mg Content of Lead Cathode

Two series of tests were made in which the concentration of magnesium in the lead cathode was allowed to build up from test to test. The results are shown in table 6.

TABLE 6. - Effect of Mg content of lead cathodeMelt: MgCl_2 with 10 percent MgO and 1 percent carbon

Cathode-current density: 5 amp. per sq. in.

Time: 3.0 hours

| Test No. | 27 | 29 | 30 | 31 | 32 ^{1/} | 33 |
|------------------------------------|------|-------|-------|-------|------------------|-------|
| Mg content of alloy, percent: | | | | | | |
| Initial | 6.46 | 12.27 | 16.33 | 51.95 | 56.82 | 60.02 |
| Final | 9.44 | 16.33 | 19.15 | 56.82 | 59.75 | 64.21 |
| Temperature, degrees C. (average). | 805 | 805 | 825 | 795 | 800 | 815 |
| Time, hours | 3.0 | 3.0 | 3.0 | 3.0 | 2.0 | 3.0 |
| Current, amp. (average) | 248 | 242 | 238 | 251 | 254 | 246 |
| Voltage (average) | 10.7 | 11.4 | 11.5 | 9.2 | 9.1 | 10.1 |
| Current efficiency, percent: | | | | | | |
| Anode | 99 | 96 | 101 | 96 | 95 | 101 |
| Cathode | 89 | 99 | 68 | 93 | 101 | 93 |
| Chlorine reacted, percent | 99 | 99 | 99 | 97 | 98 | 98 |
| Decomposition voltage (average) .. | 2.2 | 2.4 | 2.5 | 2.3 | 2.5 | 2.5 |
| Back e.m.f. (average) | 2.0 | 2.1 | 2.3 | 1.9 | 1.9 | 2.1 |

^{1/} Time, 118 minutes.

The data indicate that the magnesium content of the lead cathode has no significant effect on the current efficiencies or on the percentage of chlorine reacting. The reason for the low cathode efficiency in test 30 is not known. The melt was electrolyzed for a short time between tests 27 and 29 and between tests 32 and 33, which accounts for the slight increase in magnesium concentration between these tests. The final alloy in test 33 contained 64.2 percent magnesium by weight, or about 94 atomic percent.

Effect of Composition of Melt

The results of tests on mixtures of magnesium chloride with various other chlorides are summarized in table 7. The melt compositions are given on a solid-free basis. The weights of MgO and carbon and the volume of melt were the same as in the tests previously described, so that the number of solid particles per unit volume was constant.

In the tests with the KCl-MgCl₂ melts (tests 36 and 37), the MgO and carbon particles tended to settle and form a rather hard sludge on the surface of the alloy. Several small globules of magnesium were observed in the melt and sludge at the end of the tests, indicating that some of the magnesium had been deposited at the surface of the sludge and had risen into the melt, where it would have an opportunity to react with the anode gases. As a result, both anode and cathode efficiencies were poor. The high decomposition voltages are probably due to the formation of double salts between potassium chloride and magnesium chloride and agree fairly well with values obtained by Drossbach^{16/} for carnallite melts with an inert cathode.

No signs of sludge formation were observed in the tests on melts containing sodium chloride (tests 44 and 45). Some codeposition of sodium occurred, however. In test 44, for example, the alloy contained 0.67 percent sodium at the start (after the preliminary electrolysis to purify the melt) and 0.85 percent at the end, the over-all cathode efficiency for both magnesium and sodium being 88 percent. Weiner^{17/} found that sodium is codeposited with magnesium in the electrolysis of MgCl₂-KCl-NaCl melts with an aluminum cathode.

The cause of the relatively low cathode efficiencies in the tests with BaCl₂ and CaCl₂ (tests 40, 42, and 43) is not known. The tests progressed smoothly; there was no indication of sludge formation and no codeposition of barium or calcium. Anode erosion was considerably less than for pure MgCl₂ melts.

^{16/} Drossbach, P., (The Electrolysis of Fused Salts) : Ztschr. Elektrochem., vol. 43, 1937, pp. 891-907.

^{17/} Weiner, R., (Direct Preparation of Magnesium-Aluminum Alloys from Fused Electrolytic): Ztschr. Elektrochem., vol. 38, 1932, pp. 232-240.

TABLE 7. - Effect of composition of melt

Volume of melt constant; weight of MgO and C in each test constant at 10 percent and 1 percent, respectively, of weight of MgCl_2 in test 27.

Time: 3.0 hours.

Cathode-current density: 5 amp. per sq. in.

| Test No. | 27 | 36 | 37 | 40 | 42 | 43 | 44 | 45 |
|-----------------------------------|-------|------|------|------|------|------|------|------|
| Melt Composition, mol percent: | | | | | | | | |
| MgCl_2 | 100 | 45 | 56 | 46 | 76 | 70 | 52 | 54 |
| KCl | - | 55 | 44 | - | - | - | - | - |
| CaCl_2 | - | - | - | 54 | - | - | - | - |
| BaCl_2 | - | - | - | - | 24 | 30 | 3 | 4 |
| NaCl | - | - | - | - | - | - | 45 | 42 |
| Temperature, degrees C. . | | | | | | | | |
| (average) | 805 | 805 | 815 | 810 | 835 | 835 | 800 | 805 |
| Current, amp. (average) | 248 | 251 | 256 | 249 | 251 | 255 | 254 | 250 |
| Voltage (average) | 10.7 | 8.8 | 9.3 | 8.4 | 9.6 | 9.2 | 7.3 | 7.4 |
| Mg content of alloy, percent: | | | | | | | | |
| Initial | 6.46 | 1.67 | 3.70 | 2.07 | 1.23 | 3.35 | 1.43 | 3.52 |
| Final | 9.44 | 3.53 | 4.94 | 4.36 | 3.35 | 5.26 | 3.52 | 5.94 |
| Current eff., percent: | | | | | | | | |
| Anode | 99 | 71 | 74 | 91 | 87 | 88 | 88 | 93 |
| Cathode | 89 | 63 | 34 | 78 | 71 | 65 | 76 | 87 |
| Chlorine reacted, percent | 99 | 97 | 97 | 98 | 98 | 99 | 99 | 99 |
| Gas rate, ml. per min., S.T.P. | 1,000 | 795 | 835 | 910 | 905 | 925 | 880 | 950 |
| Analysis of gas, percent: | | | | | | | | |
| Uncorrected: | | | | | | | | |
| Cl_2 | .0 | .2 | .7 | .2 | .0 | .0 | .0 | .0 |
| COCl_2 | 1.6 | 4.2 | 3.9 | 3.0 | 3.3 | 2.0 | 2.6 | 2.5 |
| CO_2 | 80.1 | 72.5 | 69.6 | 83.2 | 75.7 | 78.1 | 82.7 | 82.5 |
| CO | 8.2 | 10.1 | 13.4 | 8.1 | 10.7 | 12.2 | 5.9 | 8.4 |
| O_2 | .2 | .6 | .6 | .8 | .3 | .5 | .6 | .9 |
| Inert | 9.9 | 12.4 | 11.8 | 4.7 | 10.0 | 7.2 | 8.2 | 5.7 |
| Corrected: | | | | | | | | |
| Cl_2 | 1.7 | 4.9 | 5.0 | 3.3 | 3.5 | 2.2 | 2.7 | 2.6 |
| CO_2 | 87.6 | 79.4 | 76.1 | 85.4 | 81.5 | 82.7 | 88.3 | 86.0 |
| CO | 10.7 | 15.7 | 18.9 | 11.3 | 15.0 | 15.1 | 9.0 | 11.4 |
| Decomposition voltage: | | | | | | | | |
| 1 hour | 2.1 | 3.0 | 2.7 | 2.5 | 2.7 | 2.5 | 2.4 | 2.8 |
| 2 hours | 2.1 | 2.9 | 3.1 | 2.4 | 2.8 | 2.3 | 2.7 | 2.5 |
| 3 hours | 2.4 | 3.0 | 2.6 | 2.3 | 2.4 | 2.6 | 2.6 | 2.6 |
| Back e.m.f.: | | | | | | | | |
| 1 hour | 1.9 | 2.8 | 2.7 | 2.2 | 2.5 | 2.2 | 2.4 | 2.4 |
| 2 hours | 2.0 | 2.7 | 2.8 | 2.3 | 2.6 | 2.2 | 2.4 | 2.4 |
| 3 hours | 2.1 | 2.6 | 2.0 | 2.2 | 2.5 | 2.3 | - | 2.3 |

Continuous Tests

To obtain further information on the electrolysis of MgCl_2 melts containing MgO and carbon, a continuous run was made lasting $4\frac{1}{2}$ days. The starting electrolyte consisted of MgCl_2 containing 10 percent MgO and 1 percent carbon; MgO , petroleum coke, and make-up MgCl_2 were added at the approximate rate of depletion. The design of the cell cover was modified so that the graphite anode could be fed forward without removing the cover assemblage. After each 6 hours of electrolysis alloy was withdrawn from the cell in a special ladle until its depth was $1\frac{1}{4}$ inches, about 5.4 pounds of lead was added to bring the depth of alloy to $1\frac{1}{2}$ inches, and the anode-cathode spacing was adjusted to $1\frac{1}{2}$ inches. During each 6-hour period the level of the alloy rose about half an inch.

Efforts were made to operate at approximately 825°C . and 250 amperes (5 amperes per square inch). The anode, however, gradually wore to a point, and the resistance of the cell increased. After about 32 hours it became necessary to lower the current to 200 amperes to prevent the temperature from rising excessively. The anode was replaced at 50.3 hours, at which time the current was returned to 250 amperes; it became necessary again to lower the current to 200 amperes at about 97 hours.

The results of the test for intervals of approximately 6 hours are summarized in table 8. The temperature, current, voltage, cathode-current efficiency, and decomposition voltage (E_d) are the averages for each period. The magnesium content of the alloy and the MgO and carbon content of the melt were determined at the end of each period, and the percentage of chlorine reacting was determined from a gas sample taken during each period.

No difficulty was experienced in operating the cell, but the run was terminated at 106.7 hours, after it had become apparent that the cell was not consuming the MgO -carbon feed as it should. During the second half of the run the melt became very viscous, and a hard sludge formed over the cathode. Samples of melt taken near the end of the run showed small globules of magnesium. It is believed that the sudden increase in cathode efficiency at 51.4 hours was due to dissolution in the molten cathode of such globules, since the bath was stirred thoroughly when the anode was replaced.

At the end of the test the contents of the cell were stirred thoroughly, and a representative sample of the bath was taken. This sample had the following composition:

Composition of bath at end of test

| | Percent |
|------------------------------------|---------|
| MgO | 22.4 |
| Carbon | 10.1 |
| FeCl_3 | 1.4 |
| SiO_2 | .5 |
| NaCl | .8 |
| Al_2O_3 | .5 |
| CaCl_2 | 22.1 |
| MgCl_2 (difference) | 62.2 |

TABLE 8. - Results of 4-1/2-day continuous test

| Period no. | Electrolysis time, hours | Average temperature, degrees C. | Average current, amperes | Average voltage | Average cathode- current efficiency, percent | ED, volts | Mg content of alloy, percent | MgO and C in melt, percent | | Chlorine reacted, percent |
|---------------|--------------------------------|--|--------------------------------|--------------------|--|--------------|--|----------------------------------|----|---------------------------------|
| | | | | | | | | MgO | C | |
| 1 | 5.6 | 829 | 248 | 9.20 | 90.5 | 2.1 | 19.4 | 10 | 1 | 94 |
| 2 | 11.5 | 837 | 250 | 8.60 | 74.2 | 2.0 | 18.7 | 13 | 6 | 98 |
| 3 | 17.6 | 825 | 250 | 9.20 | 62.4 | 2.3 | 17.3 | 8 | 5 | - |
| 4 | 23.5 | 830 | 250 | 9.55 | 77.5 | 2.5 | 17.5 | 10 | 7 | 98 |
| 5 | 29.6 | 855 | 250 | 9.71 | 55.3 | 2.0 | 16.3 | - | - | 97 |
| 6 | 35.5 | 890 | 212 | 9.80 | 67.6 | 2.3 | 15.5 | 14 | 9 | 98 |
| 7 | 41.6 | 843 | 200 | 9.64 | 69.4 | 2.6 | 14.9 | 13 | 7 | 79 |
| 8 | 48.7 | 863 | 199 | 9.72 | 36.1 | 2.3 | 14.1 | 22 | 11 | - |
| 9 | 51.4 | 829 | 227 | 7.55 | 89.4 | - | 16.8 | - | - | - |
| 10 | 57.4 | 813 | 250 | 8.47 | 32.2 | 2.1 | 13.2 | 22 | 10 | 98 |
| 11 | 63.5 | 842 | 250 | 7.47 | 38.3 | 1.6 | 12.1 | 12 | 8 | 99 |
| 12 | 68.4 | 823 | 254 | 7.04 | 24.8 | 1.5 | 10.3 | 25 | 5 | - |
| 13 | 74.5 | 824 | 250 | 7.31 | 34.6 | 1.8 | 9.9 | 21 | 12 | 97 |
| 14 | 80.5 | 834 | 253 | 7.78 | 29.2 | 1.8 | 9.2 | - | - | 99 |
| 15 | 86.5 | 867 | 249 | 8.43 | 46.6 | 2.3 | 9.9 | 11 | 8 | 79 |
| 16 | 92.5 | 842 | 248 | 8.39 | 38.6 | 2.1 | 9.8 | 10 | 6 | 99 |
| 17 | 99.5 | 885 | 239 | 8.33 | 19.7 | 1.9 | 9.0 | 24 | 14 | 96 |
| 18 | 106.7 | 875 | 204 | 8.27 | 45.1 | 2.4 | 9.5 | 20 | 9 | 97 |

Microscopic examination of the solids in the final melt indicated that at least 90 percent of the carbon present was graphitic and had evidently been formed by erosion from the anode. The sludge over the alloy, therefore, consisted essentially of MgO, graphite fragments, and magnesium globules. The low cathode efficiencies were due probably to deposition of magnesium at the surface of this sludge rather than in the molten cathode, as explained previously in the discussion of the electrolysis of KCl-MgCl₂ melts.

The graphitic carbon was much less reactive than the petroleum coke. The gas samples taken in periods 7 and 15 contained 33 percent chlorine, although 7 and 8 percent carbon, respectively, was present in the melt; in both instances the odor of chlorine was strong but disappeared rapidly upon the addition of fresh petroleum coke to the cell.

The materials balance for the test is summarized in table 9. A total of 12.57 pounds of magnesium was produced, while 22.3 pounds of MgO (corresponding to 13.4 pounds of metal) and 22.2 pounds of MgCl₂ (corresponding to 5.5 pounds of metal) were added. From the percentages of chlorine reacting, it is estimated that about 96 percent of the magnesium was produced from MgO and 4 percent from MgCl₂, so that approximately 20.0 pounds of MgO and 2.0 pounds of MgCl₂ were consumed by electrolysis. A large part of the loss of MgCl₂ may be attributed to soaking up of the melt by the new alundum crucible; part of the loss was undoubtedly due to vaporization and dusting. An unaccounted-for loss of 2.8 pounds of lead occurred during the run; in computing the cathode efficiencies given in table 8, the loss of lead was assumed to be proportional to the time.

TABLE 9. - Materials balance for 4-1/2-day continuous test

| | MgO | MgCl ₂ | Mg metal | Pb |
|---------------------------------|------|-------------------|----------|------|
| Added to cell, pounds: | | | | |
| Before electrolysis | 1.5 | 25.1 | 1.68 | 12.3 |
| During electrolysis | 25.7 | 11.7 | - | 84.8 |
| Total | 27.2 | 36.8 | 1.68 | 97.1 |
| Removed from cell, pounds: | | | | |
| At end of run | 4.6 | 12.7 | 1.63 | 15.7 |
| As samples | .3 | 1.9 | - | - |
| As alloy during test | - | - | 12.62 | 78.6 |
| Total | 4.9 | 14.6 | 14.25 | 94.3 |
| Difference, pounds | 22.3 | 22.2 | 12.57 | 2.8 |
| Consumed by electrolysis, | | | | |
| pounds (estimated) | 20.0 | 2.0 | - | - |
| Loss, pounds | 2.3 | 20.2 | - | 2.8 |

Anode consumption, as determined by the changes in the dimensions of the anodes, amounted to 0.34 pound per pound of magnesium deposited for the first anode and 0.41 for the second.

Tests with Aluminum Cathodes

Data for several tests with an aluminum cathode are given in table 10. The results, in general, are similar to those with the lead cathode. At 810° C. and 5 amperes per square inch, anode- and cathode-current efficiencies approaching 100 percent were obtained, with an MgCl_2 melt containing 10 percent MgO and 1 percent petroleum carbon. With the KCl-MgCl_2 melts the solids tended to settle on the alloy and form a thick sludge, and globules of metal were present in the melt and sludge to a much greater extent than in the corresponding tests with the lead cathode. Weiner,^{18/} who investigated the deposition of magnesium into Al-Mg cathodes from carnallite melts, states that the optimum temperature is between 600° and 640° C. (the melting point of Al-Mg alloys is below 600° C. for Mg contents between about 8 and 87 percent,^{19/}) and that at higher temperatures the formation of metal fog over the cathode seriously decreases the current efficiency. The cathode efficiency in test 46, which was made at 635° C., compares favorably with the efficiencies reported by Weiner. The low anode efficiency is probably due to the fact that the rate of evolution of gas was determined near the end of the test when the effect of sludge was most serious. It is to be noted that, in spite of the low temperature, 92 percent of the chlorine reacted. (The sodium chloride in the melt in test 46 was not added intentionally, but was picked up from the crucible, which had soaked up NaCl-MgCl_2 melt from test 45, table 7.)

TABLE 10. - Tests with aluminum cathode.

Melts contained 10 percent MgO and 1 percent carbon
Time: 3 hours

| Test No. | 34 | 38 | 39 | 46 |
|---|------|------|------|------|
| Melt composition, mol percent: | | | | |
| MgCl_2 | 100 | 54 | 48 | 47 |
| KCl | - | 46 | 52 | 39 |
| NaCl | - | - | - | 13 |
| Mg Content of alloy, percent: | | | | |
| Initial | 1.75 | 50.1 | 51.2 | 48.7 |
| Final | 12.0 | 51.2 | 52.8 | 51.7 |
| Temperature, degrees C. (average) | 810 | 813 | 815 | 635 |
| Current, amperes (average) | 251 | 255 | 251 | 149 |
| Current density, amp. per sq. in. | 5.0 | 5.1 | 5.0 | 3.0 |
| Voltage (average) | 8.2 | 7.7 | 7.8 | 6.3 |
| Current efficiency, percent: | | | | |
| Anode | 97 | 55 | 48 | 48 |
| Cathode | 96 | 20 | 23 | 76 |
| Chlorine reacted, percent | 98 | 97 | 95 | 92 |
| Decomposition voltage (average) | 2.2 | 2.7 | 2.9 | 3.2 |
| Back E.M.F. (average) | 1.9 | 2.6 | 1.9 | 2.8 |

^{18/} Weiner, R., (Direct Preparation of Magnesium-Aluminum Alloys from Fused Electrolyte): Ztschr. Elektrochem., vol. 38, 1932, pp. 232-240.

^{19/} Beck, A., The Technology of Magnesium and its Alloys; F. A. Hughes & Co., London, 3d ed., 1943, p. 47.

DISCUSSION AND CONCLUSIONS

The results of the 3-hour tests show that it is possible to electrolyze magnesium into molten lead or aluminum cathodes from magnesium chloride melts containing MgO and carbon with virtually 100-percent current efficiency and almost complete utilization of the MgO as the source of the magnesium.

One of the principal advantages of the process, aside from the high current efficiency and utilization of MgO, is that cell construction is greatly simplified. Diaphragms and baffles to prevent contact between the anode and cathode products are not needed, since the magnesium is retained in the alloy at the bottom of the cell. Similarly, there is no danger of reoxidation of magnesium by air, although the magnesium chloride must be protected against excessive oxidation by air. In practice a cell similar to the cells used in the production of aluminum probably could be used.

A difficulty that is often encountered in the electrolysis of magnesium with a solid cathode is the tendency of magnesium to form as separate globules of varying size. This tendency is increased by the presence of MgO in the bath, although it can be minimized by careful purification of the raw materials, particularly with respect to sulfates and borates. The difficulty is largely eliminated by the use of a molten cathode, so that the purity of the raw materials probably would be less critical.

One of the most important uses of magnesium is as a constituent of aluminum alloys, most of which contain 0.5 to 10 percent magnesium. For this reason aluminum appears to be the most favorable metal to use as the molten cathode, since it provides the possibility of producing (a) alloys of rather low magnesium content which would require only the addition of other alloying constituents or (b) master alloys of higher magnesium content which could be added to aluminum to give the desired magnesium content in the finished alloy.

The maximum concentration to which the magnesium content of the alloy could be raised would depend largely on the relative densities of the alloy and melt. Although accurate data are available^{20/} on the densities of binary and a few ternary melts of $MgCl_2$ with KCl , $NaCl$, $BaCl_2$, and $CaCl_2$ at various temperatures, similar data are not available on the densities of such melts containing MgO and carbon in suspension or on the densities of molten Mg-Pb or Mg-Al alloys. Test 33 (table 6) indicates that a lead alloy containing 64.2 percent Mg by weight (94 atomic percent Mg) is sufficiently more dense than magnesium chloride containing 10 percent MgO and 1 percent carbon to cause no difficulties. Weiner,^{21/} using a carnallite melt, succeeded in enriching an aluminum cathode to a magnesium content of 91.4 percent with a current efficiency of 78 percent. In view of the difficulties encountered

^{20/} Potter, E. V., and Huber, R. W., Electrical Conductivity and Density of Fused Chlorides: Bureau of Mines Rept. of Investigations. In preparation.

^{21/} Weiner, R., (Direct Preparation of Magnesium-Aluminum Alloys from Fused Electrolyte): Ztschr. Elektrochem., vol. 38, 1932, pp. 232-240.

in the present investigation with 50 percent Mg-Al cathodes, however, the production of Mg-Al alloys of high magnesium content from melts containing considerable MgO does not appear promising.

Magnesium metal may be recovered from the Pb-Mg or Al-Mg alloys by either electrolytic or distillation methods. Preliminary tests by the Bureau of Mines^{22/} have shown that Pb-Mg alloys containing 1.8 to 60 percent Mg can be electrolyzed at current efficiencies approaching 100 percent to produce magnesium metal containing less than 0.1 percent lead. According to Hanawalt, Nelson, and Peloubet,^{23/} as much as 5 percent of lead has no ill effect on the corrosion resistance of magnesium. Small amounts of lead improve machinability and do not adversely affect hardness and strength.

The boiling points of Pb-Mg and Al-Mg alloys at various concentrations have been determined by Leitgeb^{24/}. Since the boiling-point curves show no maximum or minimum, it is possible to separate magnesium (b.p., 1,097° C.) from either lead (b.p., 1,620°) or aluminum (b.p., 1,800°). The New Jersey Zinc Co.^{25/} has developed a commercial process for separating zinc (b.p., 907°) from lead and cadmium (b.p. 767°) by continuous fractional distillation, which probably would be applicable to the separation of magnesium from lead or aluminum alloys in very pure form.

The most serious problem in the electrolysis of the MgO-carbon suspensions with a molten cathode is the build-up, in long runs, of a sludge consisting largely of MgO and graphite eroded from the anode. Magnesium then tends to deposit at the surface of the sludge and form globules which remain in the sludge and aggravate the trouble or rise into the melt and react with anode gases. Among the ways by which sludge formation might be minimized are the following: (1) Reduction of anode-current density to decrease abrasion of the anode; (2) use of relatively reactive carbon anodes in place of graphite so that the abraded anode carbon would react more readily with MgO and chlorine; (3) lowering the temperature to decrease deterioration of the anodes and to minimize fog formation; and (4) increasing the specific gravity of the melt by adding calcium chloride, barium chloride, or calcium fluoride to lessen the tendency for the solid particles to settle. As a last resort, the sludge might be raked from the cell at intervals. A detailed study of the relationships of the relative densities of various melts and alloys and of the relative densities and reactivities of various forms of MgO and carbon would aid in determining the best conditions for the process.

^{22/} Zapponi, P. P., and Cartwright, Bur o, Electrolysis of Magnesium from Lead-Magnesium Alloys: Bureau of Mines War Minerals Rept. 341, 1945, 5 pp.

^{23/} Hanawalt, J. D., Nelson, C. E., and Peloubet, J. A., Corrosion Studies of Magnesium and Its Alloys: Trans. Am. Inst. Min. and Met. Eng., Inst. Metals Div., Tech. Pub. 1353, 1941, 26 pp.

^{24/} Leitgeb, W., (The Boiling of Certain Metals and Alloys at Atmospheric Pressure): Ztschr. anorg. allgem. Chem., vol. 202, 1931, pp. 305-324 (see p. 312). Beck A., The Technology of Magnesium and Its Alloys: F. A. Hughes & Co., London, 3d ed., 1943, p. 117.

^{25/} Pierce, W. M., and Waring, R. K., New Jersey Zinc Co. Process for the Refining of Zinc by Redistillation: Trans. Am. Inst. Min. and Met. Eng., vol. 121, 1936, p. 445.

Another problem that requires further investigation is the tendency of sodium to codeposit with the magnesium. Sodium is not codeposited when an iron cathode is used, even when the concentration of sodium chloride in the melt is relatively high. Under normal conditions, therefore, the deposition potential of sodium is somewhat higher than that of magnesium; Drossbach^{26/} gives the decomposition voltage of sodium chloride as 2.99 volts at 815° C. and that of magnesium chloride as 2.54 volts at 740° C. Evidently the relative deposition potentials of magnesium and sodium in lead or aluminum are altered so that they approach each other. It is possible, of course, that there is a critical concentration of sodium chloride in the melt below which no sodium would be deposited. Grube^{27/} found, for example, that in the electrolysis of $\text{MgF}_2\text{-BaF}_2\text{-NaF}$ melts saturated with MgO sodium is deposited at certain melt compositions and magnesium at others.

The data on decomposition voltages and back e.m.f.'s obtained in this investigation are not sufficiently consistent to provide much information on the effects of the operating variables on voltage. Factors that probably affect the results are the rate of diffusion of magnesium from the surface of the alloy to the interior and the relative extent to which chlorine reacts with MgO and carbon at or very near the anode and in the body of the melt. Neglecting compound formation, the theoretical reaction potential should increase by approximately 0.1 volt for each 10-fold decrease in mol fraction of MgCl_2 in the melt or each 10-fold increase in mol fraction of magnesium in the alloy. It is well-known, however, that in the solid state MgCl_2 forms the compounds $\text{MgCl}_2\cdot\text{KCl}$, $\text{MgCl}_2\cdot 2\text{KCl}$, and $\text{MgCl}_2\cdot\text{NaCl}$,^{28/} while magnesium forms the compounds Mg_4Al_3 , Mg_2Pb , and possibly MgAl and Mg_5Al_8 .^{29/} Since little is known concerning the stability of these compounds in the liquid state, their effects on the reaction potential cannot be predicted quantitatively.

SUMMARY

The use of a molten-metal cathode for the direct electrolysis of magnesium from suspensions of MgO and carbon in chloride melts greatly simplifies the cell design and, by isolating the magnesium at the bottom of the cell as soon as it is formed, increases the current efficiency.

In 3-hour tests with a magnesium chloride melt and a lead cathode, covering wide ranges of current density, temperature, and alloy composition, anodic and cathodic current efficiencies approaching 100 percent were obtained, and 95 to 99 percent of the chlorine generated reacted with the suspended MgO and carbon to form MgCl_2 , CO_2 , and CO ; the gas evolved was mostly CO_2 . In

^{26/} Drossbach, P., (The Electrolysis of Fused Salts): Ztschr. Electrochem., vol. 43, 1937, pp. 891-907.

^{27/} Grube, G., Ztschr. Elektrochem., vol. 33, 1927, p. 481.

^{28/} International Critical Tables, McGraw-Hill Book Co., New York, vol. 4, 1928, pp. 62-63.

^{29/} Beck, A., The Technology of Magnesium and Its Alloys: F. A. Hughes & Co., London, 3d ed., 1943, pp. 47, 69.

long, continuous tests, however, considerable difficulty was caused by the formation over the surface of the lead cathode of a sludge consisting largely of MgO mixed with graphite eroded from the anode.

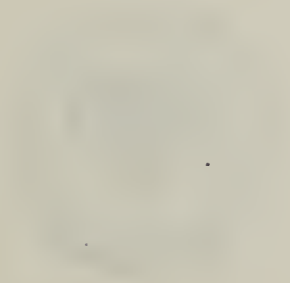
The addition of potassium chloride to the magnesium chloride lowered the density of the melt and caused sludge difficulties even in 3-hour tests. Considerable sodium was codeposited from NaCl-MgCl₂ melts. The addition of calcium or barium chloride improved the suspending properties of the melts, but lowered the current efficiencies somewhat.

Tests with molten-aluminum cathodes gave results similar to those with lead cathodes.



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UNITED STATES
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BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

CONTROL OF BULK DENSITIES IN COKE OVENS: STUDIES ON COAL USED AT THREE BYPRODUCT-COKE PLANTS



BY

W. S. LANDERS, L. D. SCHMIDT, AND WM. SEYMOUR

THE UNIVERSITY OF CHICAGO

PHYSICS DEPARTMENT

PHYSICS 309

LECTURE 10: THE HADRONIC COLLIDER

PROFESSOR J. J. HARRIS

WINTER 1997



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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

CONTROL OF BULK DENSITIES IN COKE OVENS: STUDIES ON THE COAL
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By W. S. Landers,^{2/} L. D. Schmidt^{3/} and Wm. Seymour^{2/}

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^{1/} The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3807."

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INTRODUCTION

The relative value of the various individual physical and chemical properties of coke as a measure of its performance in the blast furnace has aroused considerable controversy, but it is generally agreed that uniformity in these properties is extremely important if maximum pig-iron production is to be attained. The control of the bulk density or weight per cubic foot of the coal charge in the coke ovens is a major, and frequently overlooked, factor in producing a uniform product and in efficient operation of the coke plant.

This report presents a brief discussion of the general problem of bulk-density control and the results of tests on samples of coke-oven charges from several operating plants experiencing difficulties due to lack of adequate control. These tests covered the effect of moisture and oil content on the bulk density of the coal. Some tests on the effect of a wetting agent and fineness of grind were also made. A description of the methods used to determine the bulk density of the coals studied in this investigation and of the methods used to apply oil to the coal at byproduct-coke plants are included in this report. No theoretical analysis of the data is presented in this report, because the primary purpose of the investigation was to obtain data of immediate practical value to the plants concerned.

ACKNOWLEDGMENTS

This investigation was conducted under the direction and with the cooperation of the Coke Production Committee, composed of: A. C. Fieldner, chairman; W. C. Schroeder, secretary; W. T. Brown, consulting engineer; H. M. Chapman, Office of Solid Fuels Administration; H. M. Crossett, Bethlehem Steel Co.; W. A. Haven, Arthur G. McKee Co.; Hjalmar Johnson, Inland Steel Co.; C. D. King, U. S. Steel Corporation; A. R. Powell, Koppers Co.; Samuel Weiss, War Production Board; and H. P. Zeller, Jamison Coal & Coke Co. The authors wish to acknowledge the assistance rendered by the operators of the byproduct-coke plants visited in the course of this investigation in supplying samples and making their plant records available.

H. M. Cooper of the Bureau of Mines supervised the chemical analyses reported in this paper. H. G. Graham and J. G. Dubs of the Bureau of Mines prepared the samples and conducted the bulk-density tests reported in this study. They were assisted by F. J. Brenenborg and E. W. Donaldson.

IMPORTANCE OF BULK-DENSITY CONTROL

The weight of coal charged into a fixed oven volume is proportional to the average bulk density of the coal in the oven. Variations in the bulk density of the coal charged to different ovens result in corresponding changes in the quantity of heat required to carbonize the charges. This results in nonuniform coking or requires changes in the rate of gas consumption, flue temperatures, or coking times. In plant operation it is inefficient and extremely difficult, if not impossible, to make the required compensations in time to insure uniformity of product. The control of the bulk density of the coal provides the only practical means for obtaining uniform coking.

Pushing difficulties and damage to the ovens are apt to occur when very dry coal is charged to the ovens. The abnormally high bulk densities noted with the dry coal may cause dangerous expansion pressures with some coals or blends of coals and can be avoided by a suitable program of bulk-density control.

An important, but frequently disregarded, aspect of uniformity is that of the bulk density of the coal charge throughout a given oven. Koppers and Jenkner have measured the bulk densities at several points in a top-charged oven and found a wide variation.^{4/} They noted high densities where the coal had been subjected to impact or compression and low densities at locations where the coal had rolled into place. Under normal operating practice, under- or over-coking of portions of the charge result, causing nonuniformity of the coke. Ramsburg and McGurl^{5/} recognized the importance of this and suggested that the use of oil to control the bulk density of the charges might result in more uniform densities throughout the ovens.

FACTORS INFLUENCING BULK DENSITY

The chief causes of variation in bulk density in the coke oven are probably: (a) Fluctuations in the moisture content of incoming coal, and (b) variations in the screen analysis of the crushed coal.^{6/} Minor factors are: Variations in the specific gravity of the coal (particle size and distribution, particle shape, and condition of surface. Most coke plants can exercise fair control over the crushing of the coal by close supervision and usually can maintain the fineness of crushing within the limits desired at that plant. Few, however, are able to control the moisture content of the coal charged to the ovens.

Many investigators have shown the effect of moisture content of the coal on bulk density. In general, the bulk density of a given lot of coal decreases rapidly with increasing moisture content until a minimum is reached (usually at 4 to 6 percent moisture content) and then increases with an increase in the moisture content. Weather conditions, length of time in storage and transit, and mining conditions all affect the moisture content of the coal. Variations up to 8 percent have been noted in the moisture content of the coal charged to the ovens in one plant during a year.

POSSIBLE METHODS OF CONTROLLING BULK DENSITY OF COKE-OVEN CHARGES

Methods such as control of fineness of crushing, addition of water to dry coal, and blending of wet and dry coal are being used at a few plants

^{4/} Koppers, H., and Jenkner, A., (The Bulk Density of Top-Charged Coal): Glückauf, 1930, pp. 834-838; Fuel, vol. 9, 1930, pp. 521-526.

^{5/} Ramsburg, C. J., and McGurl, G. V., Carbonization of Coal-Oil Mixtures: Proc. Am. Gas Assoc., 1940, pp. 666-681.

^{6/} Seymour, William, and Schmidt, L. D., Control of Bulk Density of the Coal Charge in Byproduct Coke Ovens: Bureau of Mines Rept. of Investigations 3743, 1943, 13 pp.

to prevent the occurrence of densities outside of some set limits, but it is not practical to maintain constant conditions with them. If, for example, the general run of densities at a plant is to be altered, the size consist of the coal can be adjusted. The resultant charge, however, is still subject to fluctuations caused by variations in the moisture content of the coal coming into the plant. The addition of water to the coal appears to be of value only when the excessively high bulk densities encountered with dry coal are to be avoided. Although theoretically possible, apparently it is not practical to use this method to maintain uniform densities in actual plant operation.

The addition of oil to control the bulk density of the charges has been introduced recently at about 10 percent of the byproduct coke plants in this country. The chief purpose for the addition of oil is to offset the fluctuations in the bulk density of the oven charges caused by variations in the moisture content of the coal. At least one plant has a well-established and closely regulated procedure for using oil to control the bulk density of moist charges and water to lower the bulk density of excessively dry charges.

EXPERIMENTAL PROCEDURE

Methods of Measuring Bulk Density

A.S.T.M. Method

The A.S.T.M. test for determining the bulk density of crushed bituminous coal is made by allowing the coal to flow from a shovel held 2 inches above the edge of a 1-cubic foot box.^{7/} In determining bulk density by this procedure any settling of the coal by impact is carefully avoided. It is recognized that this method yields results considerably lower than those actually encountered in the coke ovens.^{8/}

Cone Method

Several modifications of the A.S.T.M. method are being used in the industry to obtain greater reproducibility. Among these are methods employing a pendulum striking against the box to produce uniform settling of the coal and charging methods in which the coal is allowed to flow from a hopper into a cubic-foot box. In this investigation tests reported as having been obtained by the "cone" method were made using a cone-shaped hopper 24-1/4 inches high, 19-1/2 inches in diameter at the top, and 4-5/16 inches in diameter at the throat.^{9/} The throat of the cone is equipped with a suitable sliding-gate valve and is supported 22-1/4 inches above the floor.

^{7/} American Society for Testing Materials, Test for Cubic-Foot Weight of Crushed Bituminous Coal (D291-29): A.S.T.M. Standards, 1942, part III, Nonmetallic Materials - General, pp. 56-57.

^{8/} Russell, C. C., Variations in the Weight per Cubic Foot of Coal: Koppers News, October 1931, pp. 1-3.

^{9/} Russell, C. C., work cited (footnote 8).

About 75 pounds of the coal is charged into the cone and allowed to discharge into the box, where it is struck off in the usual manner. As will be seen in the data presented in this report, the cone method of test yields bulk densities almost identical to those obtained by the A.S.T.M. method. There was some tendency for wet coal to hang up in the cone, and when this occurred it was necessary to start the flow by poking the coal with a rod.

Method Developed by Bureau of Mines for Measuring Bulk Density of Dropped Coal

When the coal is top-charged into a coke oven from a larry car considerable impacting of portions of the charge occurs. Since the increase in bulk density produced by this treatment varies with the moisture content of the coal, a constant correction factor applied to the A.S.T.M. results will not yield the actual densities in the oven throughout the moisture range encountered.

The method developed by the Bureau of Mines in this investigation utilizes the standard apparatus specified for the drop-shatter test for coke.^{10/} This equipment is available at most coke plants. The hopper of the apparatus is filled with approximately 200 pounds of the coal to be tested, leveled off, and raised the full 6 feet. Care is taken in filling the box to avoid segregation of the coal. The coal is allowed to drop into a rigid wooden box of 2 cubic feet capacity, centered under the hopper with its long axis parallel to the long axis of the hopper. This box is 8 x 18 x 24 inches inside dimensions and is constructed of 1-inch oak screwed and glued and externally braced to insure rigidity. After the drop, the surplus coal is struck off in the manner prescribed for the A.S.T.M. bulk density of coal test, and the box is weighed. Bulk densities determined by this method are referred to in this report as having been measured by the "dropped-coal" method. Tests on samples of the coal used for coke-oven charges obtained from two byproduct-coke plants indicate that the dropped-coal method predicts accurately the average bulk density of the coal in top-charged ovens. These tests are discussed later in this paper.

The A.S.T.M. and cone methods of determining the bulk density of the crushed coal measure the density of the coal that has been allowed to roll into position without being subjected to impact after positioning. The difference between the bulk density as measured by the cone and the dropped-coal methods is a measure of the difference between the lowest and the average densities in a given oven. Greater differences than this must actually occur in the commercial-size oven, and a higher drop and more compacting would be required in the test method to duplicate the maximum density in the oven.

Preparation of Samples

Each gross sample of coke-oven charge received from the coke plant consisted of 3,000 to 6,000 pounds of crushed coal. If the sample appeared to

^{10/} American Society for Testing Materials, Drop-Shatter Test for Coke (D141-23): A.S.T.M. Standards, 1942, part III, Nonmetallic Materials - General, pp. 73-75.

be wet, it was spread out and allowed to dry so that it could be properly sampled. When dry, the coal was divided into aliquot test samples containing approximately 250 pounds each. One of the test samples was sampled by riffing for proximate analysis and real specific gravity. The analysis of each of the coals tested is given in table 1.

The weight of water required to adjust the moisture content for each bulk-density test was calculated from the net weight of the test sample and added from a sprinkling can. The coal was quickly mixed and placed in steel drums having closely fitted, gasketed lids. Each sample was allowed to equilibrate for 48 hours so that the added water could distribute itself over the surface of the coal. The coal was then mixed for 17 hours in a rotating horizontal drum 27 inches in diameter and 60 inches in length, turning at the rate of 8 revolutions per hour. For tests requiring oil, the calculated quantity of oil was sprayed onto the coal at a rate of about 100 ml. per hour, using compressed nitrogen and a spray gun inserted through one end of the drum. During the first few tests in which oil was used it was noted that some of the oil was carried out of the drum as a mist. On subsequent tests the gases leaving the drum were passed through a glass-wool trap, and the quantity of oil lost was determined from the increased weight of the glass wool. It was found that the loss of oil as mist was less than 1 percent of the quantity of oil being used and was not significant.

TABLE 1. - Proximate analyses of coke-oven charges
studied in bulk-density investigation
(As received basis)

| Coal | | A | B | C |
|-----------------------------|-----------------------|--------|--------|--------|
| Moisture | percent ^{1/} | 2.0 | 6.0 | 1.9 |
| Volatile matter | do. | 29.0 | 31.8 | 34.1 |
| Fixed carbon | do. | 61.6 | 55.5 | 57.4 |
| Ash | do. | 7.4 | 6.7 | 6.6 |
| Sulfur | do. | .6 | 1.2 | .9 |
| B.t.u. | | 13,850 | 13,270 | 13,880 |
| Real specific gravity | | 1.353 | 1.344 | 1.335 |

^{1/} Moisture loss occurred during shipment of gross samples from plants to laboratory.

The properties of the coal spray oil used throughout this investigation are shown in table 2. It has been stated by the operators of some of the plants using oil that the type of oil used is not critical. Bunker C oil, spent wash oil, and coal spray oil have been used satisfactorily for this purpose. Ramsburg and McGurl found in plant-scale tests that coal spray oil containing petrolatum, straight coal spray oil, and Bunker C oil rated in that order in their effectiveness in increasing the bulk density of the coal in the larry car.^{11/}

^{11/} Ramsburg, C. J., and McGurl, G. V., work cited (footnote 5)

As the test sample was removed from the drum, grab samples of the coal were taken for moisture determinations and for screen analysis. It was not practical to riffle the coal to obtain the analytical samples because of the high moisture content of some of the samples being tested.

Tests Made

Bulk-density determinations were made on each test sample by the three methods described above. Repeat tests were made by each method until check results agreeing within 0.25 pound per cubic foot were obtained. Angle-of-repose measurements were made in duplicate on each sample by allowing the coal to fall from the cone onto the floor and measuring the characteristics of the pile. These tests were made to determine if a direct correlation exists between angle of repose and bulk density. The order of tests on a given sample was as follows: A.S.T.M. method, cone method, angle-of-repose measurements, and dropped-coal method. Each sample after being tested by this procedure was discarded to avoid cumulative effects of changes in the size consist of the coal.

TABLE 2. - Properties of oil used in bulk-density studies by the Bureau of Mines^{1/}

| | | |
|------------------------|-----------------|---------------|
| Gravity | °A.P.I. | 26.2 |
| Specific gravity | 60/60° F. | 0.8973 |
| Pour point | °F. | Less than 5 |
| Water | percent | Less than 0.1 |
| Ash | do. | None |
| Viscosity: | | |
| 33° F. | Saybold seconds | 979 |
| 77° F. | do. | 197 |
| 100° F. | do. | 110 |

^{1/} Coal spray oil furnished by the Standard Oil Co. of Pennsylvania. Properties determined by the Bureau of Mines, Bartlesville, Okla.

RESULTS OF TESTS

Coal A

A 5,500-pound sample of the coal charged to the ovens was obtained from plant A, which produced furnace coke from a blend of 75 percent high-volatile and 25 percent low-volatile unwashed coals. At times the moisture content of the coal going to the ovens was high due to rain or snow and varied from 1.8 to 7.6 percent. The average moisture content of the coke-oven charges at this plant was 4.4 percent over a period of 1 year. During this same period, the average screen analysis of the coal charged to the ovens showed 86.9 percent passing a 1/8-inch screen and 94.6 percent passing a 1/4-inch screen.

To avoid excessively high bulk densities and possible danger to the ovens, it was the practice at this plant to add water to the coal when very dry coal was being charged. When very wet coal was being used, dry coal was occasionally mixed in to reduce the average moisture content of the

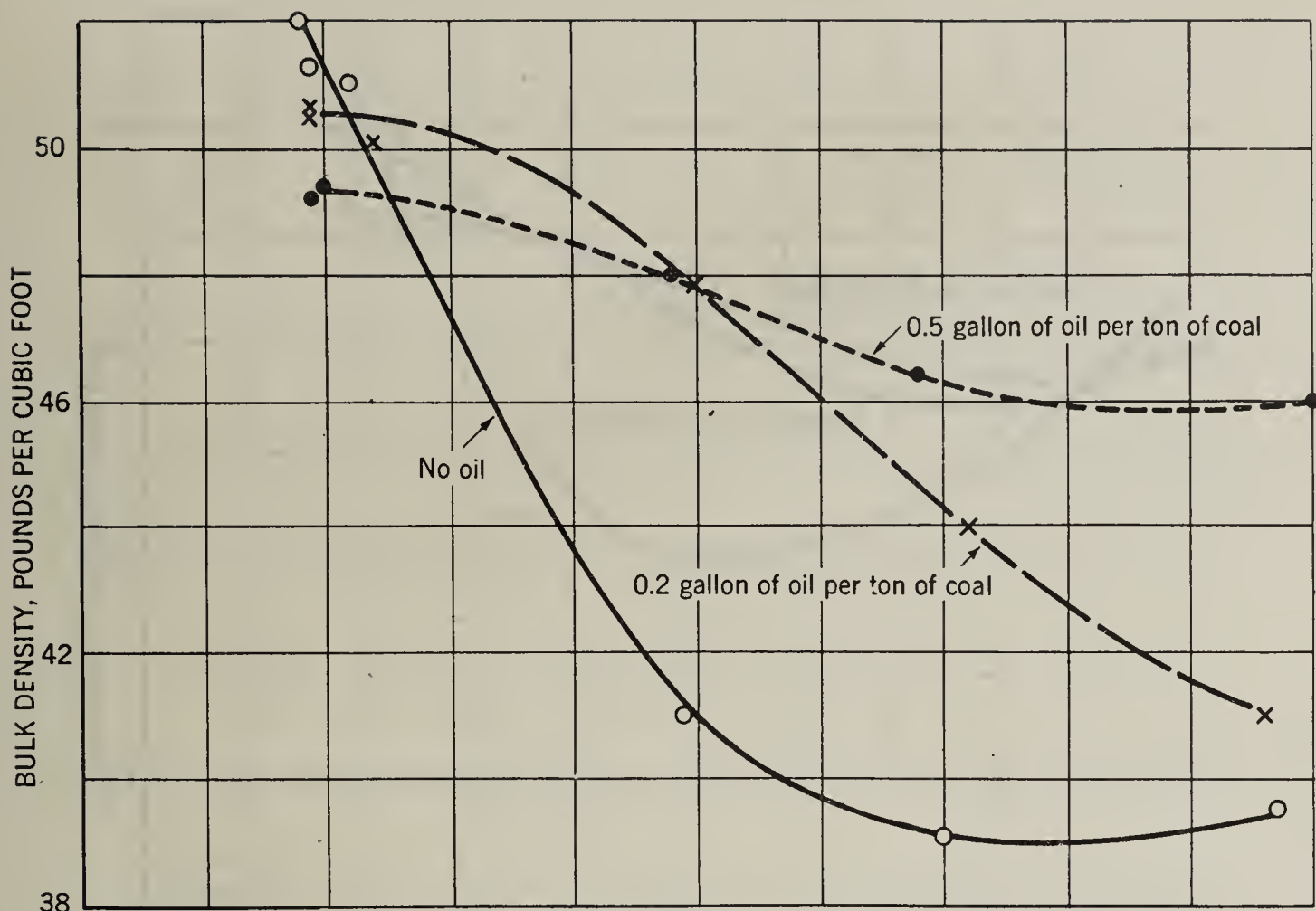


FIGURE 1.- Relation of bulk density of coal A to its moisture content. A. S. T. M. method.

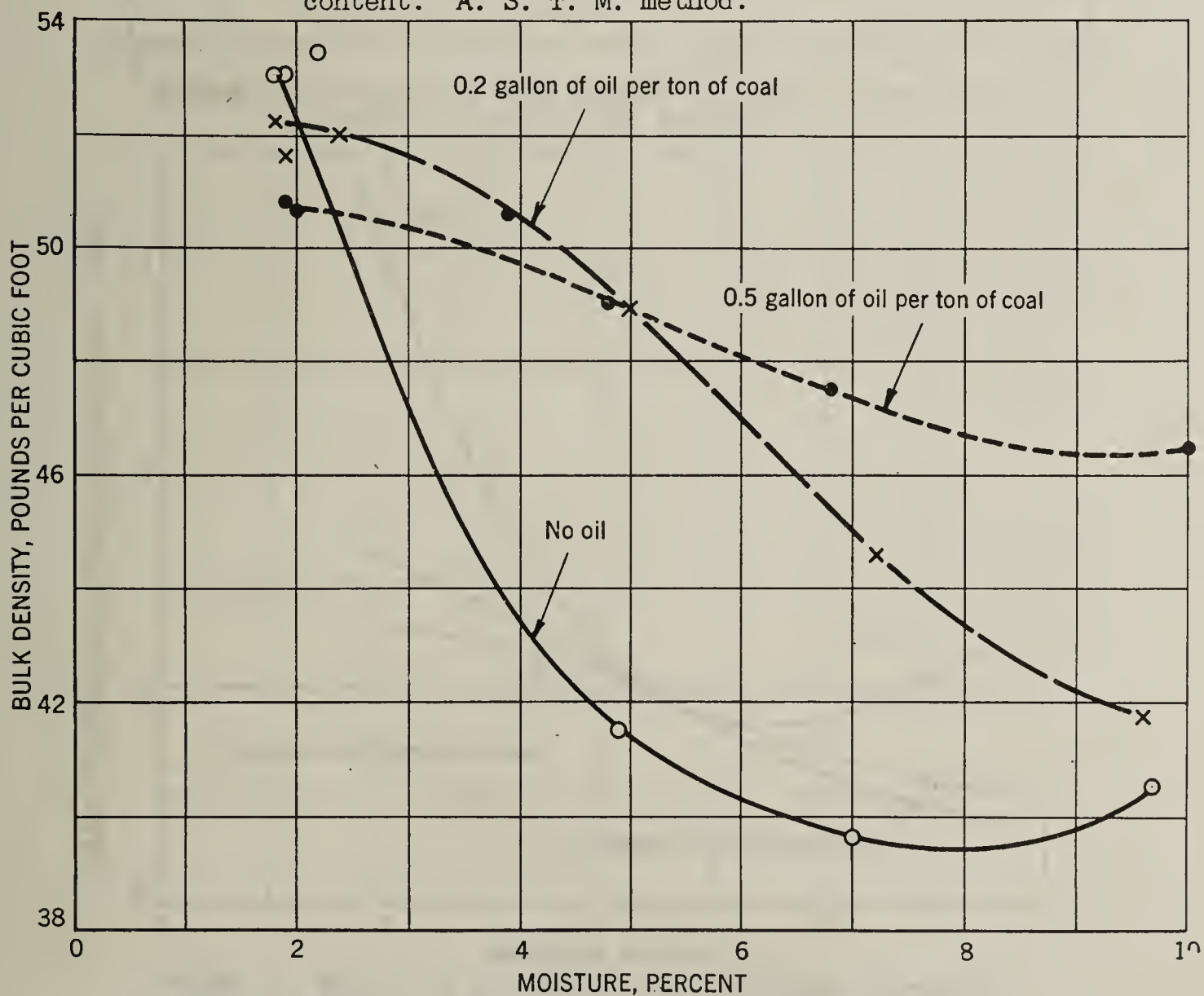


FIGURE 2.- Relation of bulk density of coal A to its moisture content. Cone method.



Graph 1: $y = \sin(x)$ and $y = \cos(x)$



Graph 2: $y = \sin(x)$ and $y = \cos(x)$

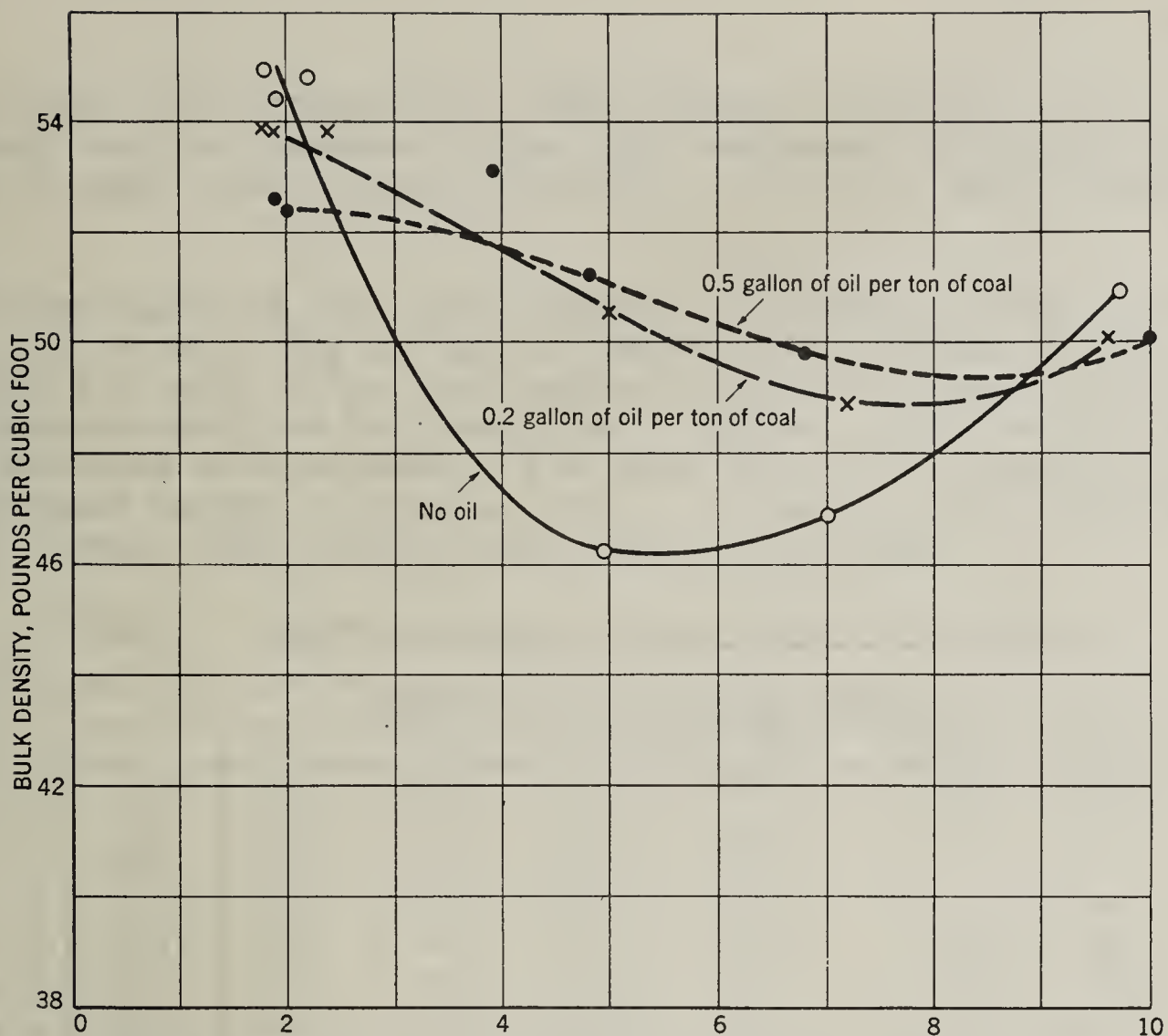


FIGURE 3.- Relation of bulk density of coal A to its moisture content. Dropped-coal method.

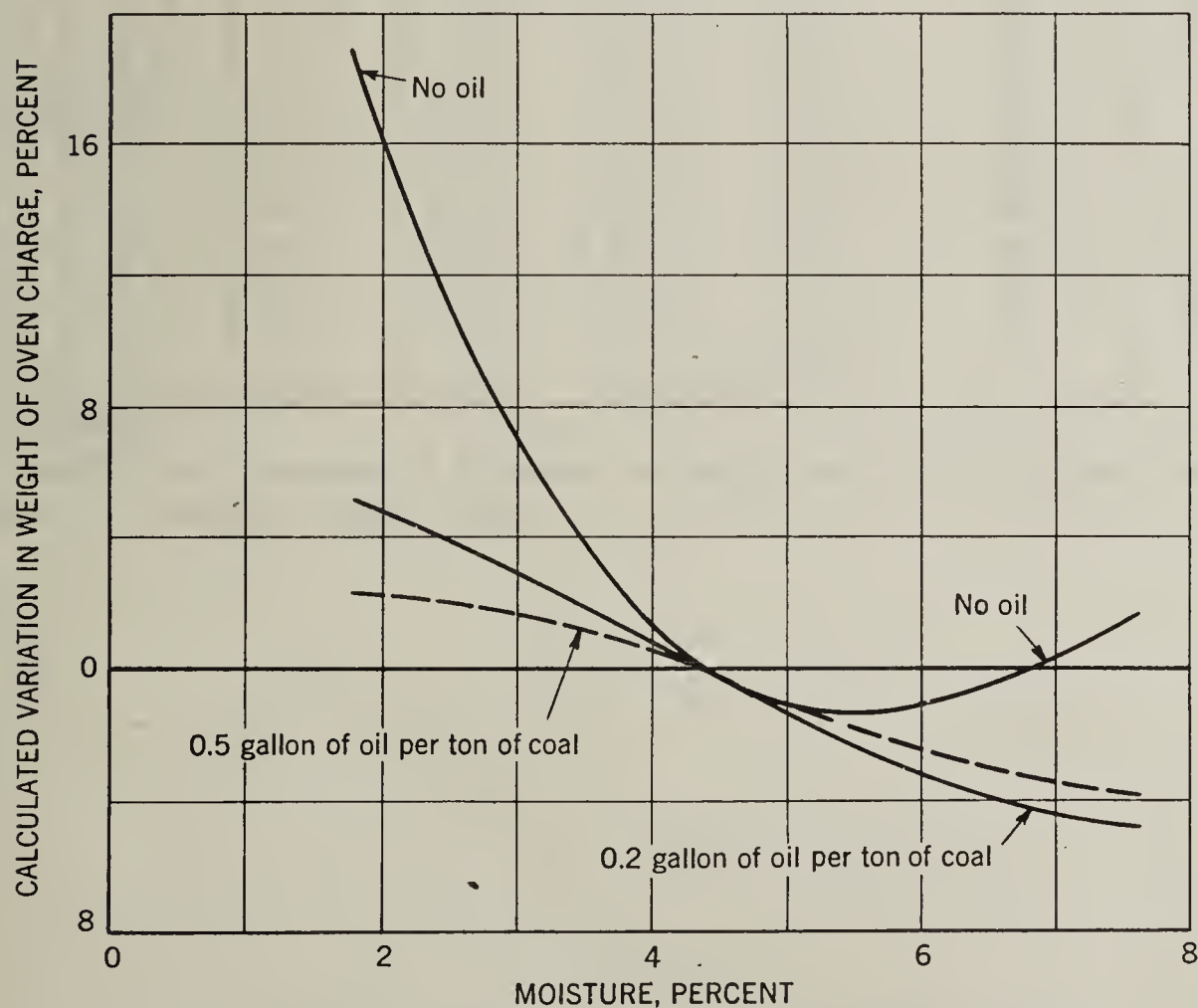


FIGURE 4.- Effect of oil addition on variation in weight of oven charges throughout moisture range at plant A. (Ovens charged by volume.)



charge and raise its bulk density. These methods of control were not very satisfactory, and the operators of the plant requested information that would assist them in devising and installing a better system of bulk-density control.

The large sample of coal A was sampled and tested by the procedure outlined in this report, using 0.2 and 0.5 gallon of oil per ton of coal. The sieve analysis of each of the test samples of coal A is given in table 3 and their moisture content and bulk densities in table 4. To show the trends, the bulk densities as determined by the three methods have been plotted against moisture content in figures 1 to 3. In table 4, the calculated weight of moisture-free coal per cubic foot is also shown.

TABLE 3. - Sieve analyses of test samples of coal A

| Screen size ^{1/} | Cumulative percentage retained | | | | | | | |
|---------------------------|--------------------------------|------|------|------|--------------------|------|------|-----|
| | 4 | 8 | 14 | 35 | 80 | 150 | 200 | Pan |
| A-01..... | 7.8 | 25.5 | 46.8 | 71.3 | 84.0 | 89.3 | 91.8 | 100 |
| A-02..... | 8.1 | 21.9 | 40.5 | 67.2 | 82.4 | 89.0 | 92.7 | 100 |
| A-03..... | 8.4 | 22.4 | 42.0 | 69.0 | 85.1 | | | 100 |
| A-05..... | 7.6 | 22.3 | 42.8 | 69.3 | 83.7 | 89.4 | 92.1 | 100 |
| A-06..... | 6.4 | 20.1 | 40.0 | 67.7 | 83.8 | 89.8 | 92.6 | 100 |
| A-07..... | 5.5 | 18.4 | 37.5 | 65.9 | 83.4 | 90.8 | 94.9 | 100 |
| A-08..... | 7.0 | 21.7 | 42.8 | 69.6 | 83.5 | 89.1 | 91.8 | 100 |
| A-09..... | 6.4 | 20.5 | 41.0 | 68.3 | 84.5 | 90.8 | | 100 |
| A-10..... | 5.9 | 19.2 | 39.4 | 66.9 | 82.4 | 88.9 | 92.3 | 100 |
| A-11..... | 6.3 | 21.2 | 42.1 | 69.1 | 83.9 | 90.1 | 92.9 | 100 |
| A-12..... | 6.6 | 20.4 | 40.5 | 68.1 | 83.6 | 90.1 | 93.4 | 100 |
| A-13..... | 7.3 | 20.4 | 41.0 | 68.9 | 84.4 | 91.0 | | 100 |
| A-14..... | 6.5 | 19.2 | 38.9 | 67.4 | 82.6 | 88.4 | 91.2 | 100 |
| A-15..... | 7.1 | 20.5 | 40.3 | 67.5 | 82.6 | 88.8 | 92.1 | 100 |
| A-16..... | 9.5 | 22.2 | 40.8 | 68.3 | 84.1 | 90.3 | 93.7 | 100 |
| A-17..... | 7.0 | 22.6 | 42.6 | 70.0 | 84.4 | 90.2 | 93.2 | 100 |
| A-18..... | 5.6 | 19.2 | 39.3 | 68.5 | 84.1 | 90.5 | 94.3 | 100 |
| A-19..... | 5.5 | 18.2 | 38.0 | 67.9 | ^{2/} 88.3 | | | 100 |

^{1/} Tyler screens.

^{2/} Screen analysis inaccurate because of agglomeration of the fines caused by the oil added to the coal.

TABLE 4. - Bulk densities of test samples of coal A

| Test No. | Moisture, percent | Oil added, gallon per ton ¹ / | Bulk density, pounds per cubic foot | | | | | |
|-----------|-------------------|--|-------------------------------------|------------------------------------|-----------|-------------|------------------------------------|---------------------|
| | | | A.S.T.M. method | | | Cone method | | |
| | | | As tested | Moisture-free basis ² / | As tested | As tested | Moisture-free basis ² / | Dropped-coal method |
| A-01..... | 1.8 | 0 | 52.0 | 51.1 | 53.0 | 54.9 | 52.0 | 53.9 |
| A-08..... | 1.9 | 0 | 51.2 | 50.2 | 53.0 | 54.4 | 52.0 | 53.4 |
| A-14..... | 2.2 | 0 | 51.0 | 49.9 | 53.4 | 54.8 | 52.2 | 53.6 |
| A-11..... | 4.9 | 0 | 41.0 | 39.0 | 41.5 | 46.2 | 39.5 | 43.9 |
| A-04..... | 7.0 | 0 | 39.1 | 36.4 | 39.6 | 46.8 | 36.8 | 43.5 |
| A-17..... | 9.7 | 0 | 39.5 | 33.9 | 40.5 | 50.9 | 36.6 | 46.0 |
| A-02..... | 1.8 | 0.2 | 50.5 | 49.6 | 52.2 | 53.9 | 51.3 | 52.9 |
| A-10..... | 1.9 | .2 | 50.6 | 49.6 | 51.6 | 53.8 | 50.6 | 52.8 |
| A-15..... | 2.4 | .2 | 50.1 | 48.9 | 52.0 | 53.8 | 50.8 | 52.5 |
| A-12..... | 5.0 | .2 | 47.9 | 45.5 | 48.9 | 50.6 | 46.5 | 48.1 |
| A-06..... | 7.2 | .2 | 44.0 | 40.8 | 44.6 | 48.9 | 41.4 | 45.4 |
| A-18..... | 9.6 | .2 | 41.0 | 37.1 | 41.8 | 50.1 | 37.8 | 45.3 |
| A-03..... | 1.9 | .5 | 49.2 | 48.3 | 50.8 | 52.6 | 49.8 | 51.6 |
| A-09..... | 2.0 | .5 | 49.4 | 48.4 | 50.6 | 52.4 | 49.6 | 51.4 |
| A-16..... | 3.9 | .5 | 49.9 | 48.0 | 50.6 | 53.1 | 48.6 | 51.0 |
| A-13..... | 4.8 | .5 | 48.0 | 45.7 | 49.0 | 51.2 | 46.6 | 48.7 |
| A-07..... | 6.8 | .5 | 46.4 | 43.2 | 47.5 | 49.8 | 44.3 | 46.4 |
| A-19..... | 10.0 | .5 | 46.0 | 41.4 | 46.5 | 50.1 | 41.9 | 45.1 |

¹/ Coal spray oil. For properties, see table 2.²/ Moisture-free density = as-tested bulk density x (100 - moisture, percent).

100

DROPPED-COAL BULK DENSITY MINUS CONE
BULK DENSITY, POUNDS PER CUBIC FOOT

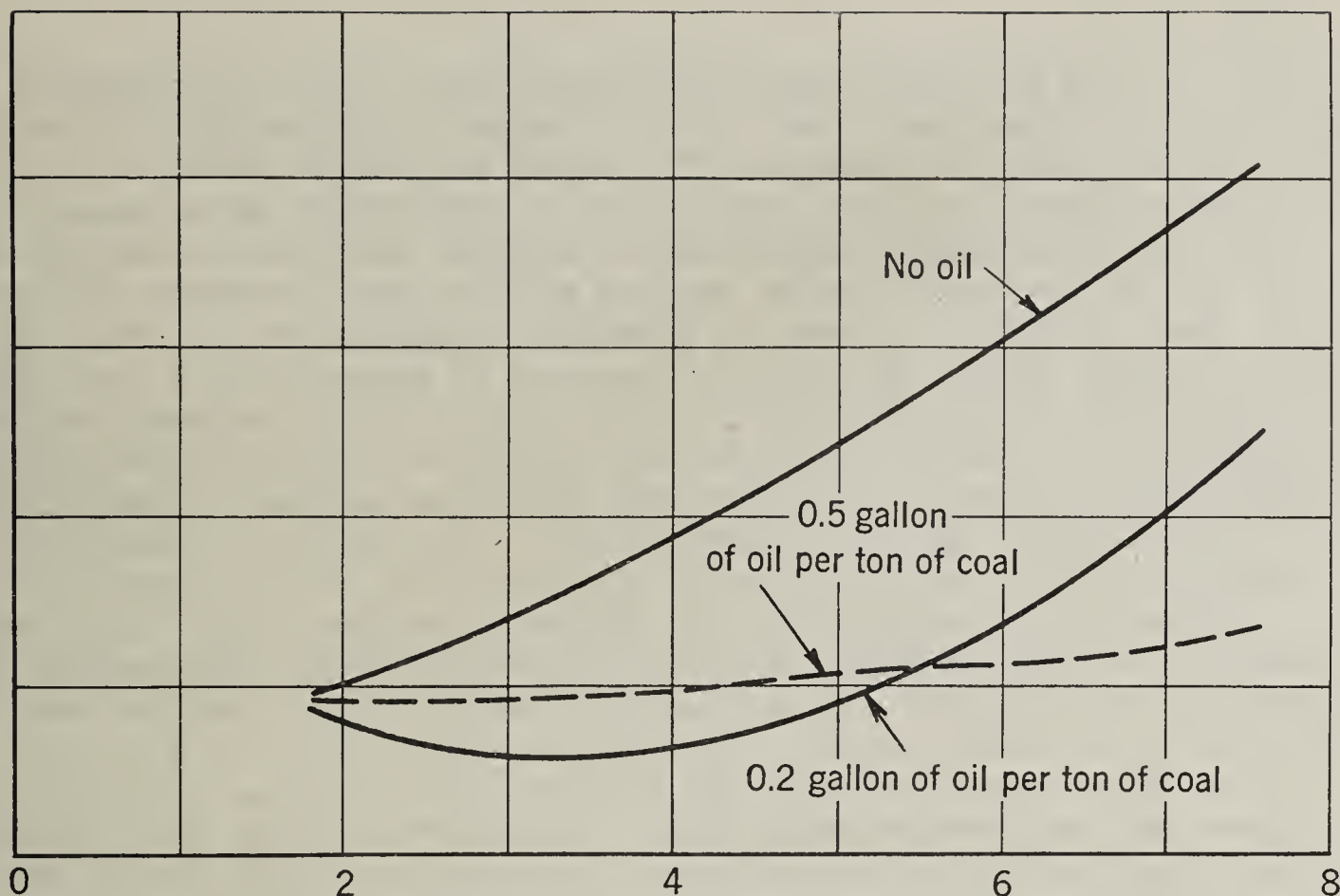


FIGURE 5.- Increase in bulk density of oiled and unoiled coal A caused by dropping coal.

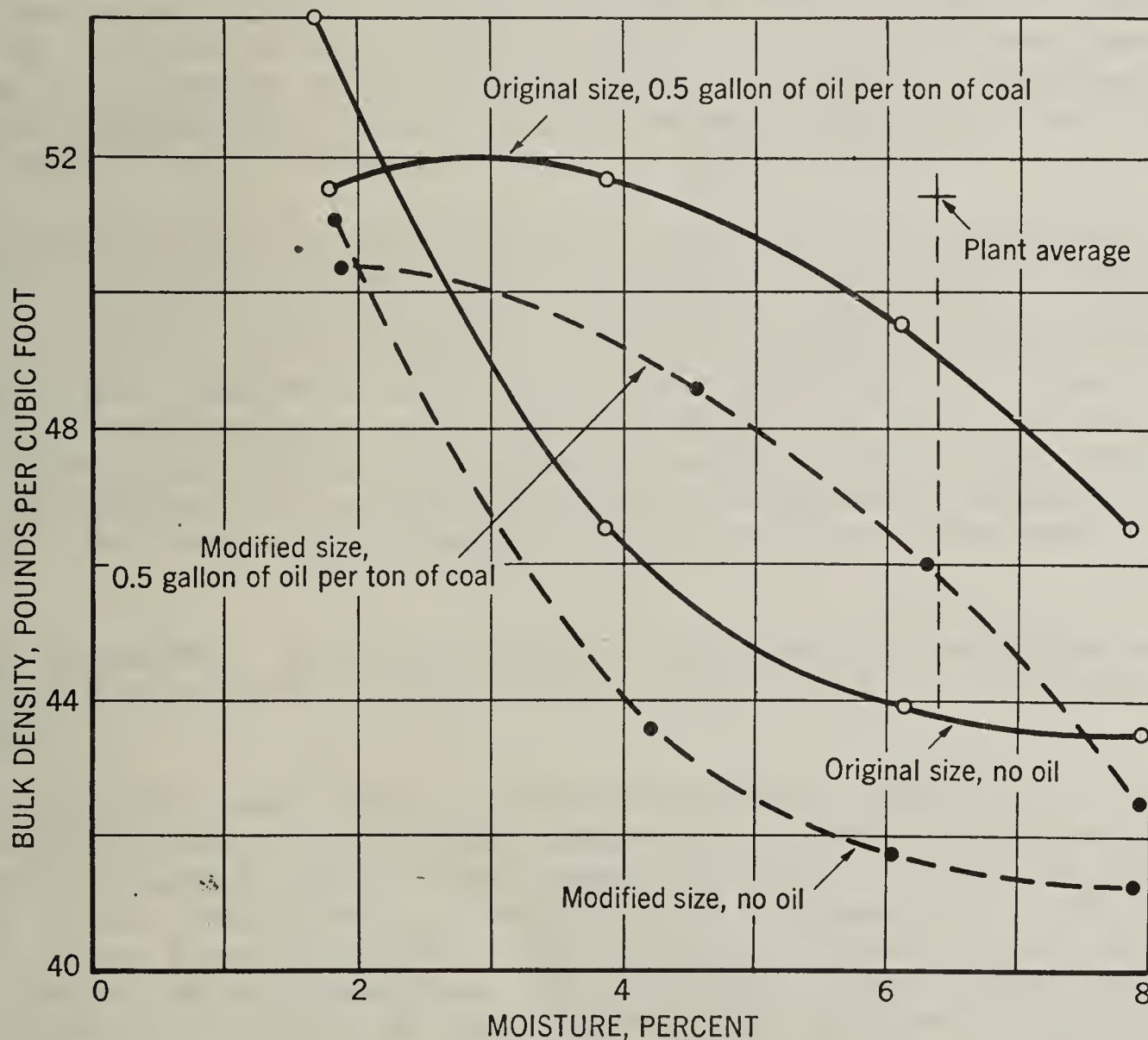


FIGURE 6.- Relation of bulk density of coal B to its moisture content. A. S. T. M. method.

The weight of coal in an oven charged by volume with coal A can be calculated from figure 3 if the moisture content of the coal, the quantity of oil added per ton, and the oven volume are known. The standard or base weight of oven charge is taken to be the weight of charge when the coal contains the average moisture content of the coal charged at the plant. When charging coal A containing 4.4 percent moisture (the average moisture content of the coal charged at plant A) the standard charge of an oven of 480 cubic feet capacity would be: 22,400 pounds if the coal is unoiled, 24,600 pounds if the coal has been treated with 0.2 gallon of oil per ton, or 24,700 pounds if the coal has been treated with 0.5 gallon of oil per ton. When charging coal containing 3.0 percent moisture, the weight of an oven charge would be 24,000 pounds of unoiled coal, 25,400 pounds of coal treated with 0.2 gallon of oil per ton, or 25,100 pounds of coal treated with 0.5 gallon of oil per ton. The increase in weight of oven charges at 3.0 percent moisture content over their respective standard charges would be 7.1 percent for the unoiled coal, 3.2 percent for the coal treated with 0.2 gallon of oil, and 1.6 percent for the coal treated with 0.5 gallon of oil. The results of similar calculations covering the plant moisture range of 1.8 to 7.6 percent are shown in figure 4. This figure shows that the weight of the oven charge when unoiled coal is charged would vary as much as 18.6 percent from the standard weight of charge throughout the moisture range found at the plant. If 0.2 gallon of oil were added per ton of coal, the maximum variation would be 5.1 percent from the standard, and it would be reduced to 3.8 percent if 0.5 gallon of oil per ton of coal were used. The addition of 0.5 gallon of oil per ton of coal A charged to the ovens should reduce the maximum variation between the weight of individual oven charges to 31 percent of the difference noted with unoiled coal.

The sensitivities of the oiled and unoiled coals to packing are shown in figure 5. In this figure, the differences between the bulk densities as measured by the cone and dropped coal methods (calculated from figures 2 and 3) have been plotted against the moisture content. It is seen that the differences found with the oiled coal are less than those found with the unoiled coal; in other words, the bulk density of the oiled coal changes less with dropping and impacting than does that of the unoiled coal. If the drop test were severe enough to indicate the maximum charge density in the oven, it is probable that greater differences would be noted.

It is apparent, therefore, that the bulk densities throughout an oven charged with oiled coal A should be more uniform than if unoiled coal is charged.

As mentioned above, this plant has been adding water when dry coal is being used in order to avoid excessively high densities in the ovens and this practice agrees with the data shown in figure 3. Since the bulk density of the unoiled coal is very sensitive to changes in the moisture content in the lower range, very close supervision would be required to obtain controlled bulk densities. On the samples tested containing less than 2.0 percent moisture, it was found that the addition of oil reduced the bulk density and that the reduction was larger when 0.5 gallon of oil

was used than with 0.2 gallon of oil per ton of coal. This effect should aid in preventing oven damage due to excessive bulk densities.

No angle-of-repose measurements were made on coal A.

Coal B

A 3,500-pound sample of this coke-oven charge was obtained from plant B, which produced furnace coke from a blend of 84 percent washed high-volatile coal and 16 percent unwashed low-volatile coal. The following data were obtained on coal charged at this plant over a period of 1 year: Average moisture content, 6.41 percent; range of moisture content, 5.1 to 7.4 percent; average fineness of crushing, about 50 percent through a 1/8-inch square-hole screen; average bulk density by A.S.T.M. method, 45.4 pounds per cubic foot; and calculated average bulk density of the coal in the ovens, 51.4 pounds per cubic foot.

The average bulk density of the coal in the ovens at this plant was considered satisfactory by the operators. They felt that higher bulk densities might result in damage to the ovens while lower ones would reduce the throughput of the plant. They were interested in controlling the fluctuations in the bulk density of the coal in the ovens caused by the variations in the moisture content of the coal charged. The operators also desired a method by which the fineness of grind could be increased without altering the present average operating density of the coal in the ovens. The survey engineers suggested that one possible method of altering the size consist of the coal at this plant would be to remove the plus 3/8-inch material from the present material, recrusher this oversize to pass the 3/8-inch screen, and recombine the total coal. This procedure is interesting in that it suggests a method of controlling bulk density by control of the size consist by recycling some of the coal through the crusher. Further work is now being done to develop this possibility. The gross sample was divided into two identical samples, and the first of these was split into two portions. The effect of moisture on the bulk density of the plant coal was determined on one of these, and the other portion was used to determine the effect of the addition of 0.5 gallon of oil per ton of coal on the bulk density throughout the same moisture range used with the unoiled coal. The plus 3/8-inch coal was screened from the remaining half of the original gross sample and crushed in a laboratory hammer mill to all pass the 3/8-inch screen. This crushed material was then recombined with the original minus 3/8-inch coal and thoroughly mixed. This sample was then split into aliquot portions and tested with and without oil. The sieve analyses of the individual test samples are shown in table 5. The results of the bulk density determinations made by the three methods are given in table 6 and have been plotted against moisture content in figures 6 to 8. The calculated weight of moisture-free coal per cubic foot in each test is also shown in table 6.

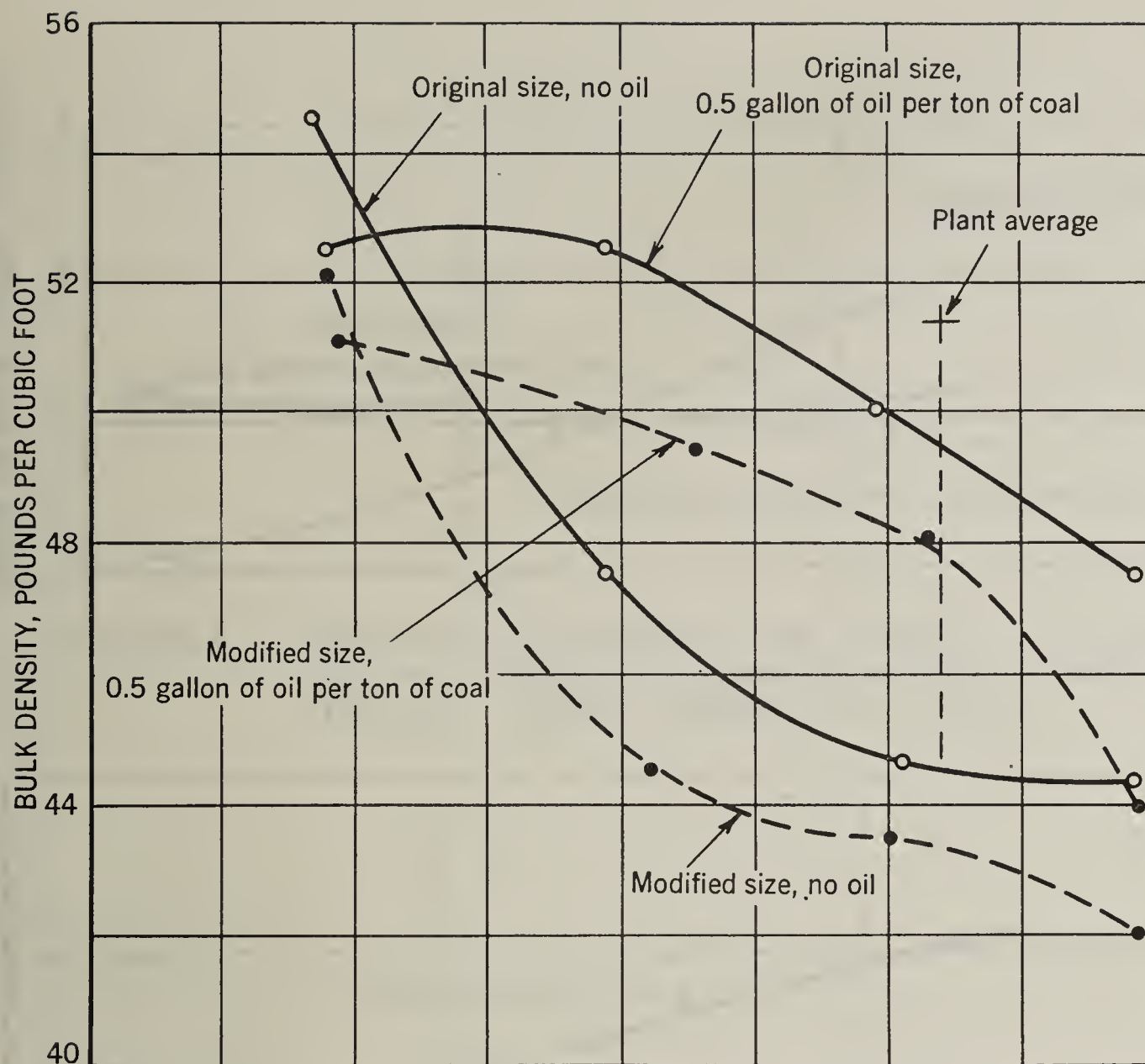


FIGURE 7.- Relation of bulk density of coal B to its moisture content. Cone method.

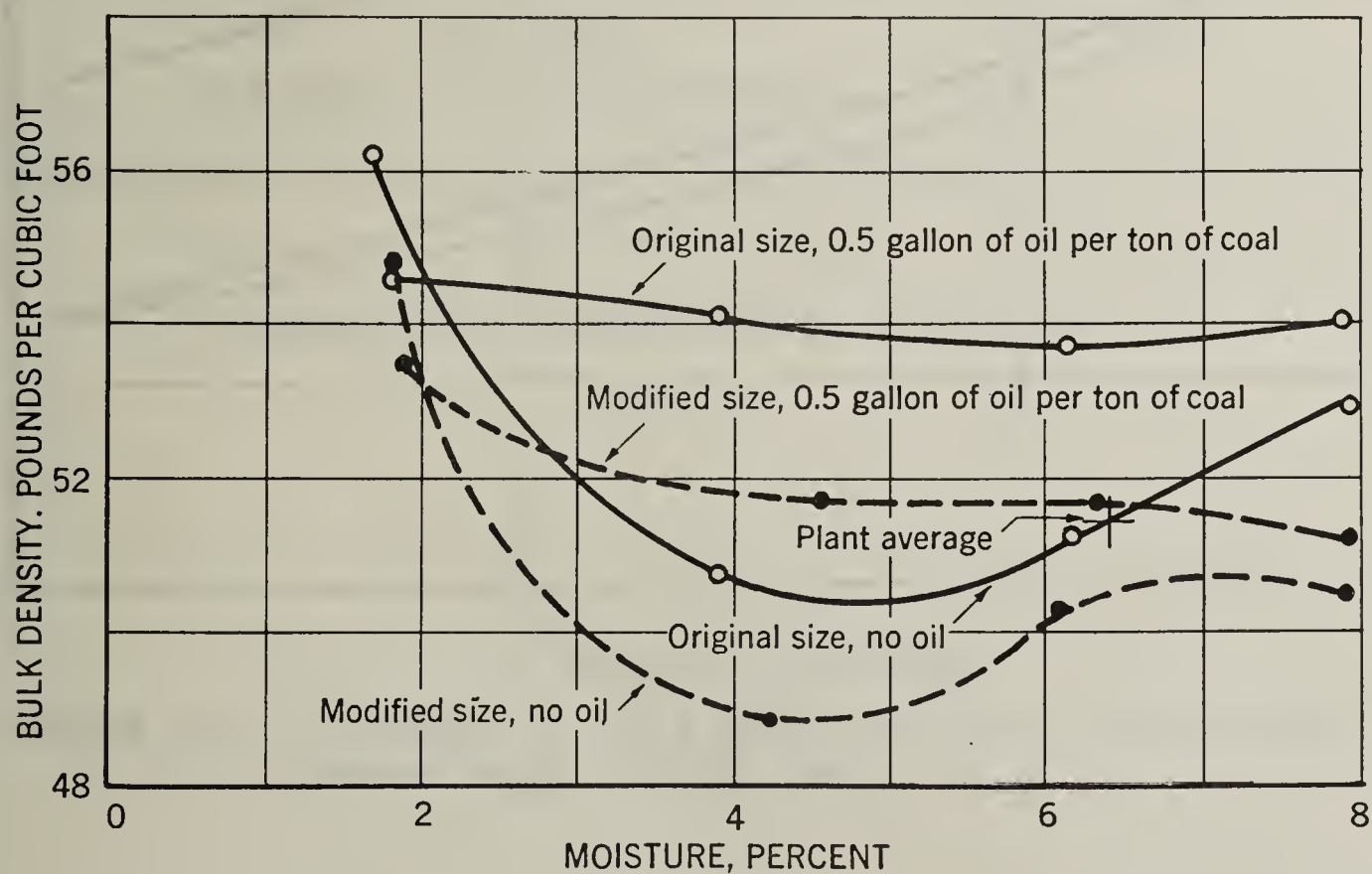


FIGURE 8.- Relation of bulk density of coal B to its moisture content. Dropped-coal method.



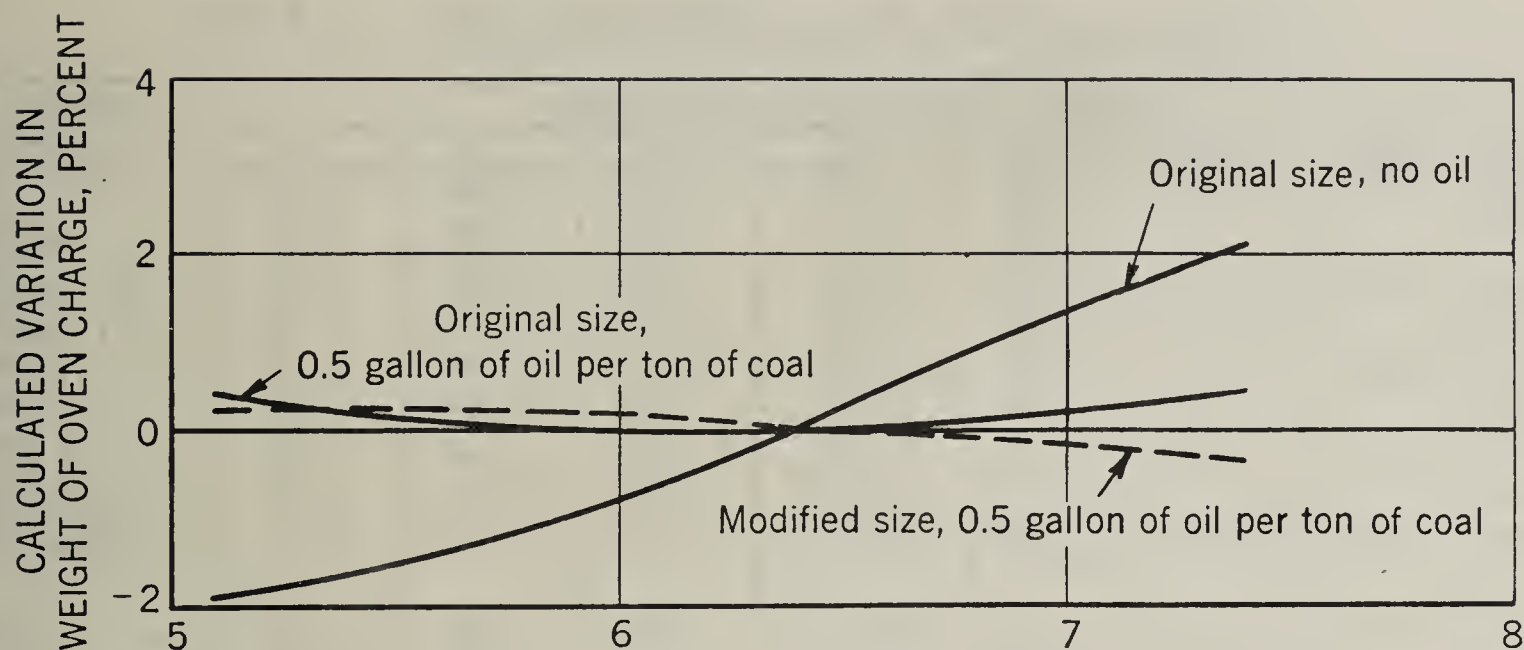


FIGURE 9.- Effect of oil addition on variation in weight of oven charges throughout moisture range at plant B. (Ovens charged by volume.)

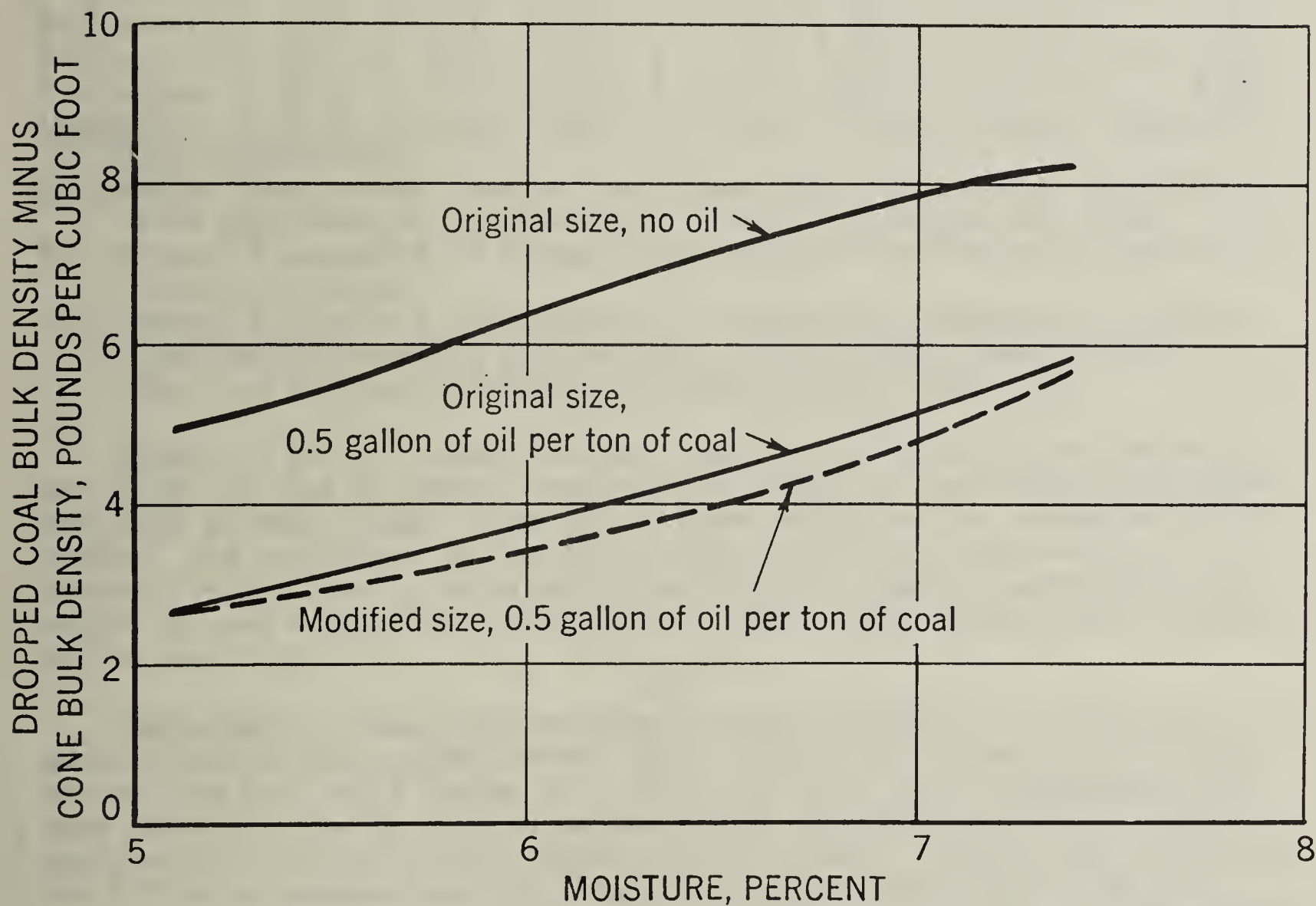


FIGURE 10.- Increase in bulk density of oil and un-oiled coal B caused by dropping coal.

Figure 1. Effect of temperature on the rate of polymerization of styrene in benzene solution.



Figure 1 shows the effect of temperature on the rate of polymerization of styrene in benzene solution. The rate of polymerization increases with increasing temperature, and the effect is more pronounced at higher temperatures. The rate of polymerization also increases with increasing concentration of benzoyl peroxide.

Figure 2. Effect of concentration of benzoyl peroxide on the rate of polymerization of styrene in benzene solution.



Figure 2 shows the effect of concentration of benzoyl peroxide on the rate of polymerization of styrene in benzene solution. The rate of polymerization increases with increasing concentration of benzoyl peroxide, and the effect is more pronounced at higher temperatures. The rate of polymerization also increases with increasing temperature.

TABLE 5. - Sieve analyses of test samples of coal B

| Screen size ^{1/} | Cumulative percentage retained | | | | | | | |
|---------------------------|--------------------------------|------|------|--------------------|------|------|------|-----|
| | 4 | 8 | 14 | 35 | 80 | 150 | 200 | Pan |
| B-01..... | 31.6 | 48.6 | 64.6 | 81.4 | 89.6 | 93.0 | 94.7 | 100 |
| B-02..... | 22.9 | 38.6 | 56.5 | 77.4 | 89.1 | | | 100 |
| B-03..... | 28.2 | 45.5 | 62.4 | 81.3 | 90.6 | 94.2 | 95.9 | 100 |
| B-04..... | 27.9 | 45.0 | 61.9 | 81.4 | 91.5 | | | 100 |
| B-05..... | 27.0 | 44.1 | 60.8 | 80.5 | 89.9 | 93.6 | 95.4 | 100 |
| B-06..... | 27.2 | 44.9 | 62.3 | 82.2 | 92.4 | | | 100 |
| B-07..... | 26.7 | 44.3 | 61.6 | 80.1 | 89.2 | 92.6 | 94.4 | 100 |
| B-08..... | 24.3 | 42.1 | 59.7 | ^{2/} 90.5 | | | | 100 |
| Average ^{3/} ... | 27.0 | 44.1 | 61.2 | 80.6 | 90.3 | 93.4 | 95.1 | 100 |
| B-09..... | 18.2 | 39.6 | 58.7 | 78.9 | 88.6 | 92.5 | 94.7 | 100 |
| B-10..... | 17.1 | 34.6 | 53.2 | 76.5 | 88.0 | 92.6 | | 100 |
| B-11..... | 17.0 | 37.2 | 56.3 | 78.1 | 88.9 | 93.0 | 95.0 | 100 |
| B-12..... | 17.4 | 38.6 | 57.7 | 79.4 | 90.8 | 94.7 | | 100 |
| B-13..... | 17.9 | 38.5 | 57.4 | 78.8 | 88.7 | 92.5 | 94.5 | 100 |
| B-14..... | 16.5 | 37.1 | 56.4 | 79.3 | 90.7 | 94.7 | | 100 |
| B-15..... | 16.5 | 37.6 | 57.9 | 78.7 | 88.5 | 92.3 | 94.3 | 100 |
| B-16..... | 16.7 | 37.1 | 56.7 | 79.1 | 90.5 | 94.8 | | 100 |
| Average ^{4/} ... | 17.2 | 37.5 | 56.8 | 78.6 | 89.3 | 93.4 | 94.6 | 100 |

^{1/} Tyler screen sizes.

^{2/} Deleted from average because inaccuracy in screen analysis resulting from agglomeration of fine sizes by the oil added to the coal.

^{3/} Average of samples B-01 through B-08 representing samples of coal as crushed at plant.

^{4/} Average of samples B-09 through B-16 representing samples of the coal modified by screening out the plus $3/8$ -inch coal, crushing this fraction to pass $3/8$ -inch and recombining the total coal.

Figures 9 and 10 present the same analyses of the data for coal B as were made for coal A, namely, variation in weight of oven charge throughout the plant moisture range from the standard weight at the average moisture content, and the effect on the bulk density of dropping the coal. It is apparent from figure 9, calculated from figure 8, that the uniformity of weight of oven charges when charging by volume should be increased greatly by the use of oil.

The weight of coal per oven when charging unoiled coal B might vary as much as 4.0 percent between ovens. The addition of 0.5 gallon of oil per ton of this coal would reduce this to 0.4 percent, and the maximum difference noted between the weights of individual oven charges of the oiled, modified size coal B probably would be 0.8 percent. In addition, from figure 9 it will be seen that addition of oil to the coal modified by the crushing and recombining of the oversize resulted in an almost uniform bulk density throughout the moisture range noted at the plant. The bulk density of this series of samples in this moisture range, as determined by the dropped-coal method, varied from 51.7 to 51.4 pounds per cubic foot, while the average operating bulk density that the operators wish to maintain is

51.4 pounds per cubic foot. At the average plant-moisture content of 6.4 percent, the bulk density of the unoiled, unmodified coal B determined by the dropped-coal method was the same as the calculated average bulk density of the coal in the ovens at the plant.

The effect of oil treating in decreasing the sensitivity of the coal to compression by drop and impact is shown in figure 10. The addition of oil should result in a more uniform density of the coal throughout a given oven than when unoiled coal is charged.

The results of the angle-of-repose measurements are shown in figure 11. It can be seen that the angle of repose of unoiled coal increased with increasing moisture content of the coal. The data are consistent with plant experience, since it is well-known that wet coal does not flow as easily as dry coal and that wet coal often gives trouble in discharging bins and hoppers. On the oiled samples, the angles of repose at low moisture contents were higher than those of the corresponding unoiled samples at the same moisture content. With increasing moisture content, the angle of repose of the oiled samples decreased until a minimum was reached at about 6 percent moisture content. Beyond this point the angle of repose of these samples showed a sharp increase. Although a relation between the angle of repose and bulk density can be established for each of the four series of tests on coal B, there does not seem to be any general relationship between these two measurements. Modification of the size consist is seen to have a significant effect on the bulk density of both the oiled and unoiled samples but appeared to have no appreciable effect on the angle of repose.

The results of the tests on coal B indicate that the application of oil to this coal will increase the bulk density beyond desirable limits. However, if the plus 3/8-inch material is removed and crushed to minus 3/8-inch and recombined with the rest of the coal, the addition of 0.5 gallon of oil per ton of coal will make the bulk density of the resultant material practically independent of the moisture content throughout the moisture range studied and will level it off at the present operating average density in the ovens. No doubt at the plant the bulk density of the oven charges could also be maintained at the desired level by merely crushing all the coal finer and using oil.

Coal C

A 4,000-pound sample of coke-oven charge was obtained from plant C, which produces furnace coke from a blend of 83 percent high-volatile and 17 percent low-volatile coal. None of the coal used at this plant was washed, and the fluctuations in the moisture content of the coal were caused by rain, snow, and the taking of changing percentages of output from wet portions of the mine. Over a 2-month period at this plant, moisture content varied from 1.97 to 3.21 percent and the fineness of crushing from 50.8 to 86.0 percent through a 1/8-inch screen. This plant charges by volume up to a set maximum weight. The average bulk density in the ovens was calculated as 50.2 pounds per cubic foot over a period in which the moisture content of the charges averaged 2.23 percent. Since the "drag", or coal removed by the leveler bar, is greatest when the full larry-car volume is used, the fluctuation in the net weight of oven charges is accentuated.

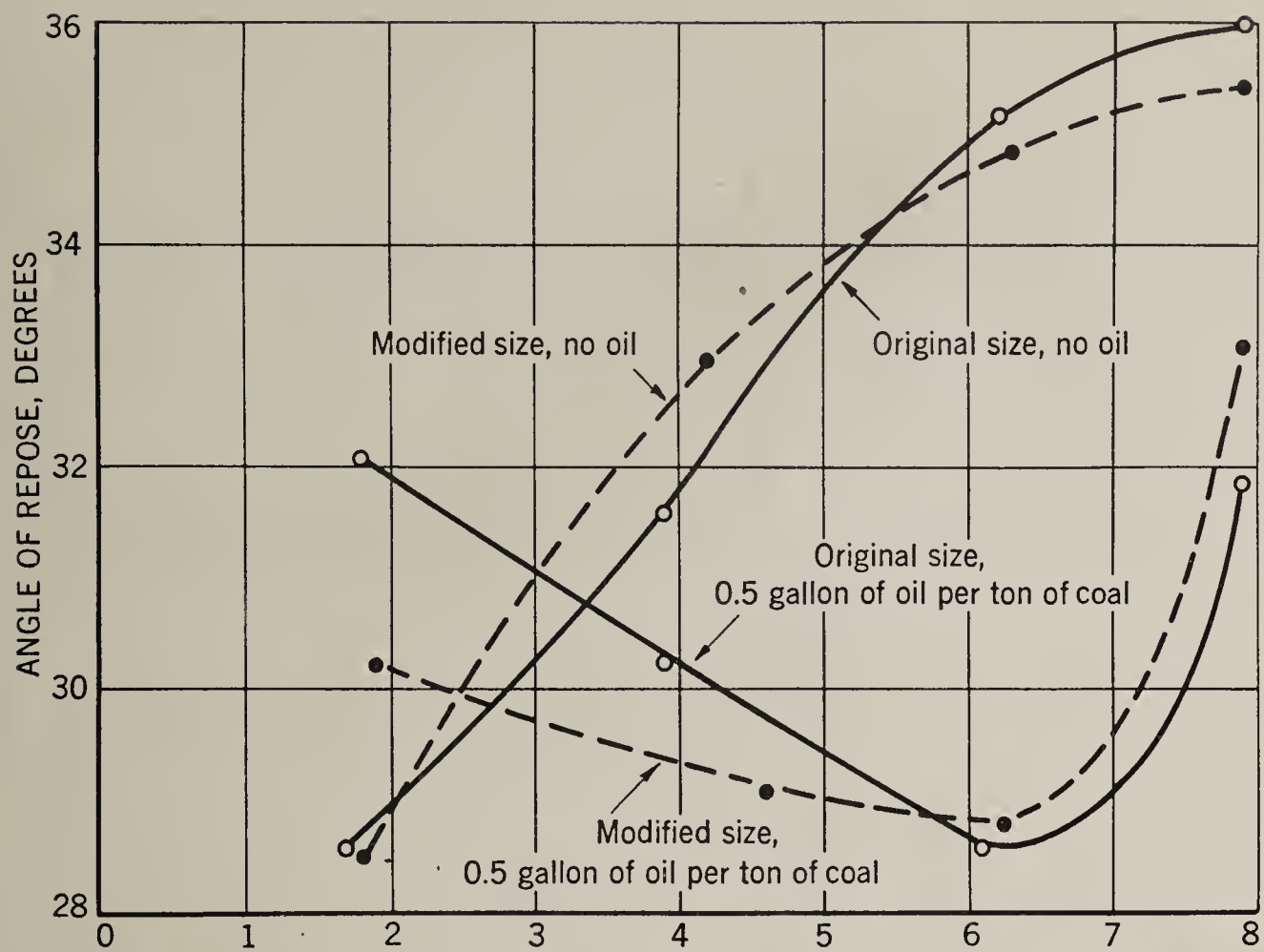


FIGURE 11.- Relation of angle of repose and moisture content of coal B.

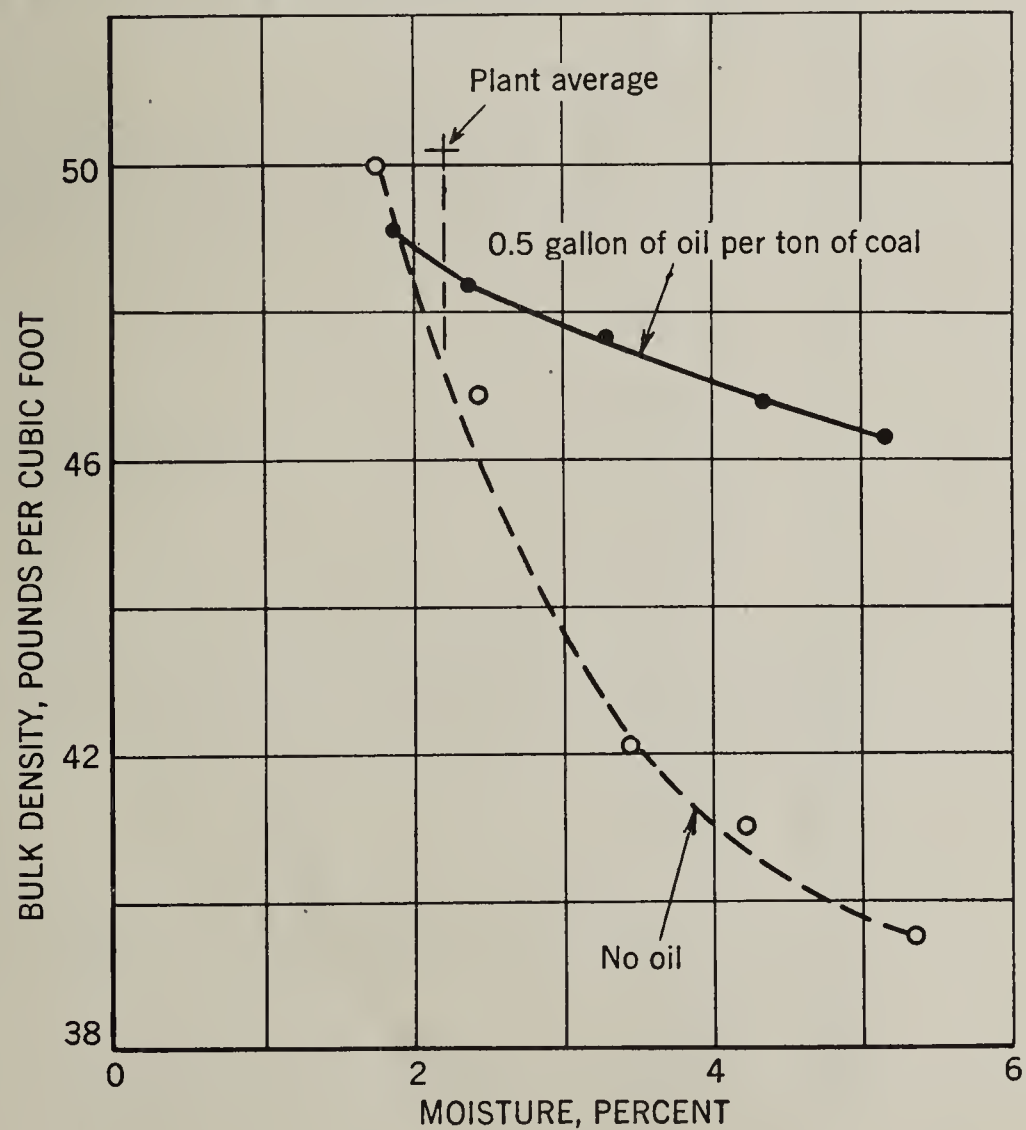


FIGURE 12.- Relation of bulk density of coal C to its moisture content. A. S. T. M. method.

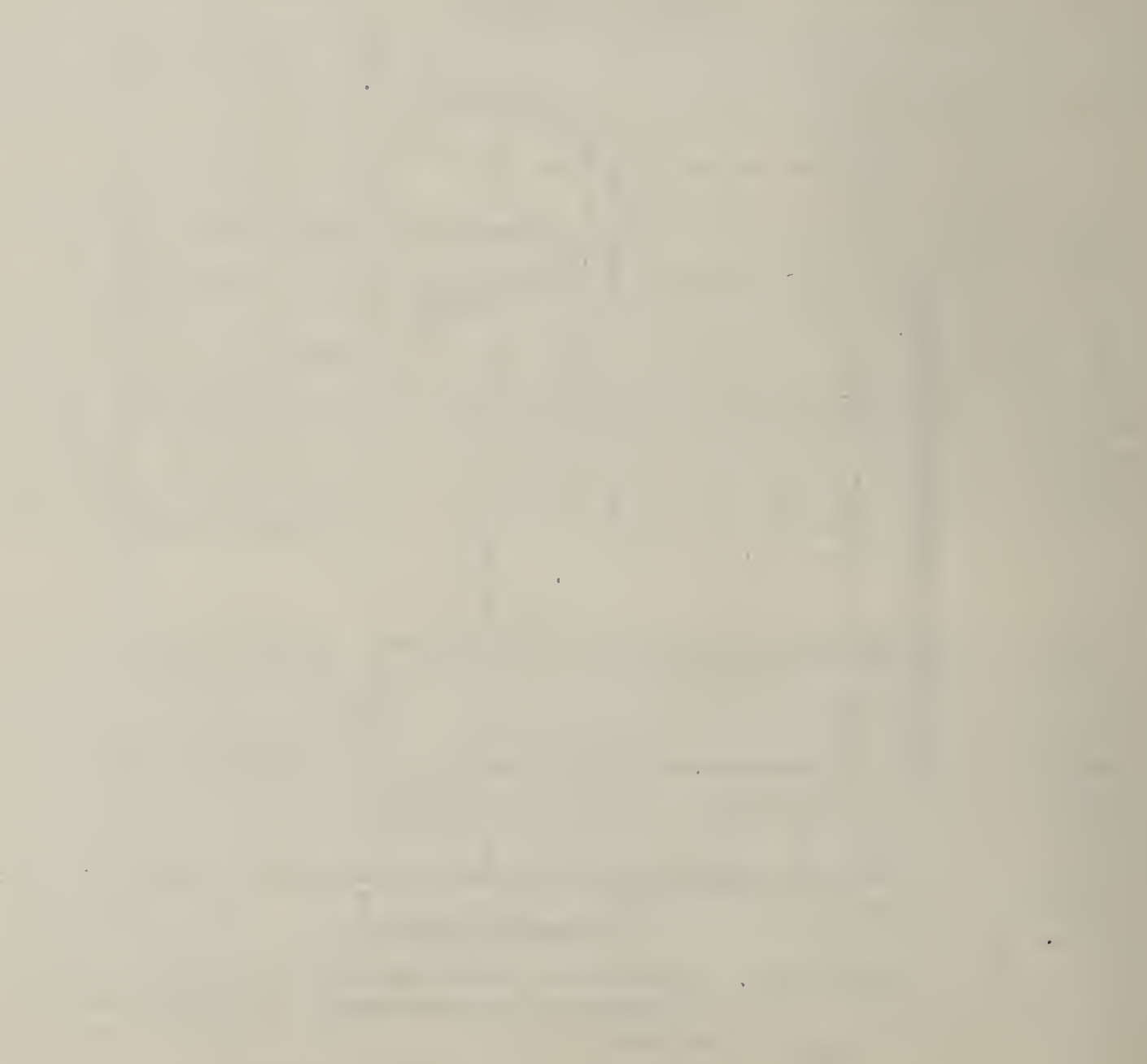


TABLE 6. - Bulk densities of test samples of coal B

| Test No. | Coal size | Moisture, percent | Oil added, gallon per ton ¹ / | Bulk density, pounds per cubic foot | | | |
|-----------|-------------------------|----------------------|--|-------------------------------------|---------------------------------------|--------------|---------------------------------------|
| | | | | A.S.T.M. method | | Cone method | |
| | | | | As tested | Moisture-free basis ² / | As tested | Moisture-free basis ² / |
| B-01..... | Original ³ / | 1.7 | 0 | 53.9 | 53.0 | 54.5 | 53.6 |
| B-03..... | do. | 3.9 | 0 | 46.5 | 44.7 | 47.5 | 45.6 |
| B-05..... | do. | 6.2 | 0 | 43.9 | 41.2 | 44.6 | 41.8 |
| B-07..... | do. | 7.9 | 0 | 43.5 | 40.1 | 44.3 | 40.8 |
| B-02..... | do. | 1.8 | 0.5 | 51.5 | 50.6 | 52.5 | 51.6 |
| B-04..... | do. | 3.9 | 0.5 | 51.6 | 49.6 | 52.5 | 50.5 |
| B-06..... | do. | 6.1 | 0.5 | 49.5 | 46.5 | 50.0 | 47.0 |
| B-08..... | do. | 7.9 | 0.5 | 46.5 | 42.8 | 47.6 | 43.8 |
| B-09..... | Modified ⁴ / | 1.8 | 0 | 51.2 | 50.3 | 52.2 | 51.3 |
| B-11..... | do. | 4.2 | 0 | 43.6 | 41.8 | 44.3 | 42.4 |
| B-13..... | do. | 6.0 | 0 | 41.8 | 39.3 | 43.3 | 40.7 |
| B-15..... | do. | 7.9 | 0 | 41.3 | 38.0 | 42.0 | 38.7 |
| B-10..... | do. | 1.9 | 0.5 | 50.3 | 49.3 | 51.2 | 50.2 |
| B-12..... | do. | 4.6 | 0.5 | 48.6 | 46.4 | 49.3 | 47.0 |
| B-14..... | do. | 6.3 | 0.5 | 46.0 | 43.1 | 48.1 | 45.1 |
| B-16..... | do. | 7.9 | 0.5 | 42.4 | 39.1 | 44.0 | 40.5 |

¹/ Coal spray oil. For properties, see table 2.

²/ Moisture-free bulk density = as-tested bulk density x $\frac{100 - \text{moisture, percent}}{100}$.

³/ As received from coke plant.

⁴/ Plus 3/8-inch coal removed, crushed to pass 3/8-inch, and recombined.

The operators of this plant were interested in a method of bulk-density control that would reduce the fluctuations in the weight of oven charges. High bulk densities were experienced when dry coal was charged and the operators felt that dangerous expansion pressures developed. To control this, the operators added water to the dry coal, but this had not proved completely satisfactory, since it required constant attention. The operators requested information on a system of bulk-density control that would:

- (1) Permit them to maintain their present operating average density in the ovens.
- (2) Reduce the fluctuations being experienced.
- (3) Eliminate the excessively high densities encountered with the dry coal.

Coal C from this plant was tested by the same procedure used with the previous samples. The screen analysis of each of the test samples is given in table 7, and the results of the bulk-density tests made on this coal are shown in table 8 and in figures 12 to 14. The relation between angle of repose of the oiled and unoiled samples and moisture content is given in figure 15.

In addition to the tests made on coals A and B, tests were made to determine the effect of a small quantity of wetting agent on the bulk density of the oiled and unoiled coal. These tests are included in the data of table 8. In adjusting the moisture content of the test samples, water containing 1 percent of laboratory aerosol by weight was used on samples C-11 to C-14, inclusive. An examination of the data indicates that no significant or consistent change was produced by the use of the wetting agent on either the oiled or the unoiled coal samples at the moisture contents used.

The average bulk density of the coal in the ovens at the plant was 50.2 pounds per cubic foot during a period in which the moisture content of the oven charges averaged 2.23 percent. From figures 12 to 14 it can be seen that the bulk densities at this moisture content as determined in the laboratory were: 47.1 pounds per cubic foot by the A.S.T.M. method, 48.1 pounds per cubic foot by the cone method, and 50.4 pounds per cubic foot by the dropped-coal method. Thus the dropped-coal method again checks actual average oven densities with very pleasing accuracy.

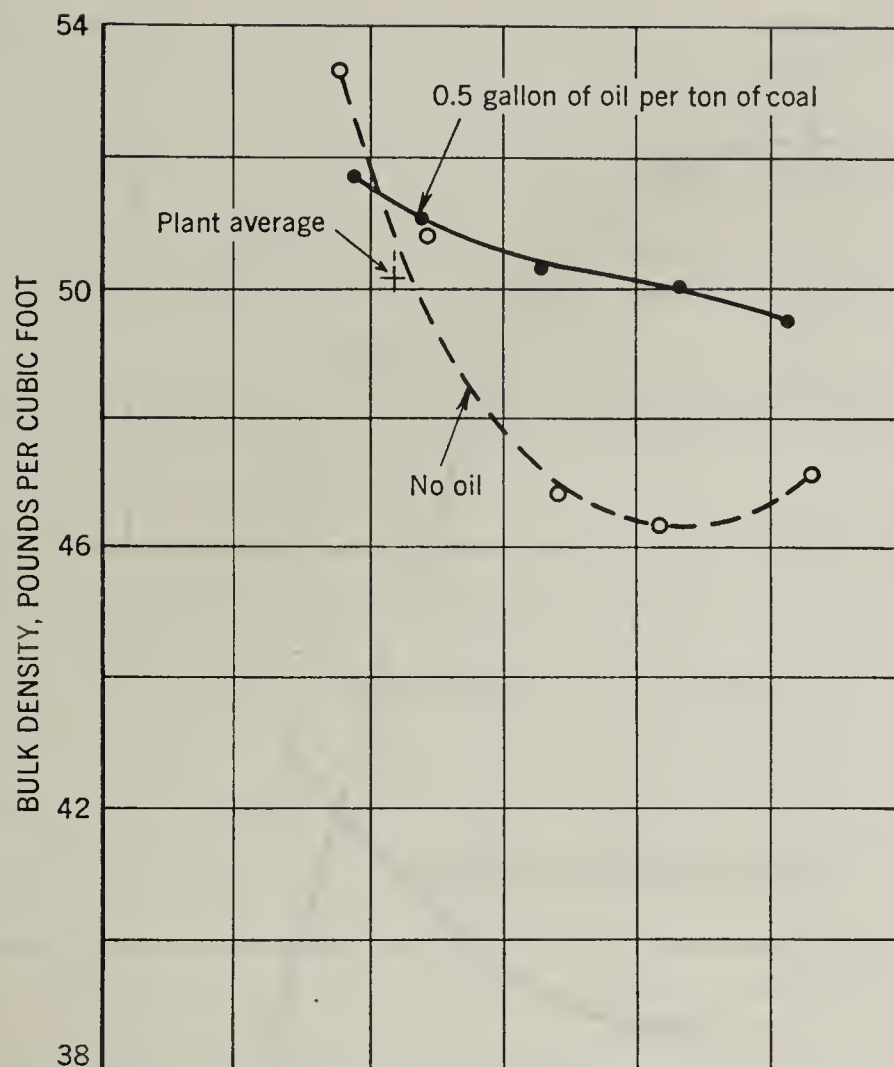


FIGURE 13.- Relation of bulk density of coal C to its moisture content. Dropped-coal method.

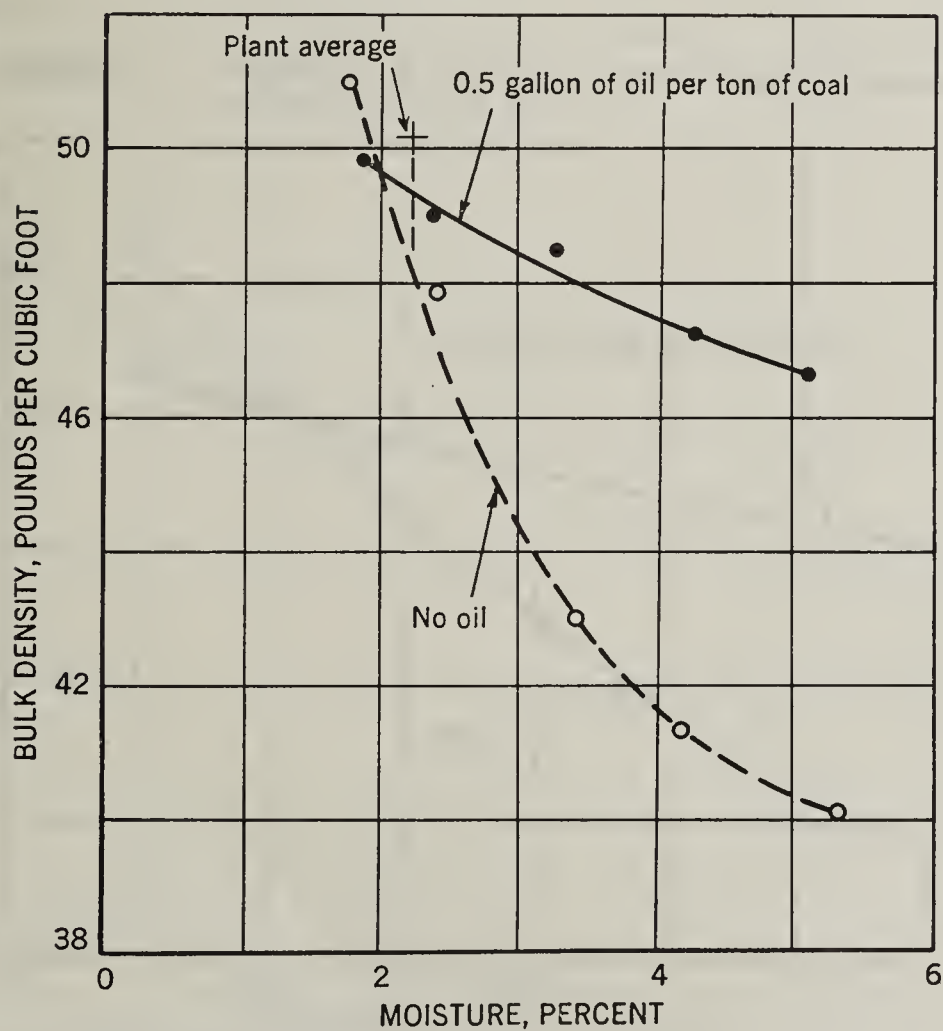


FIGURE 14.- Relation of bulk density of coal C to its moisture content. Cone method.



Graph of Temperature vs. Time



Graph of Temperature vs. Time

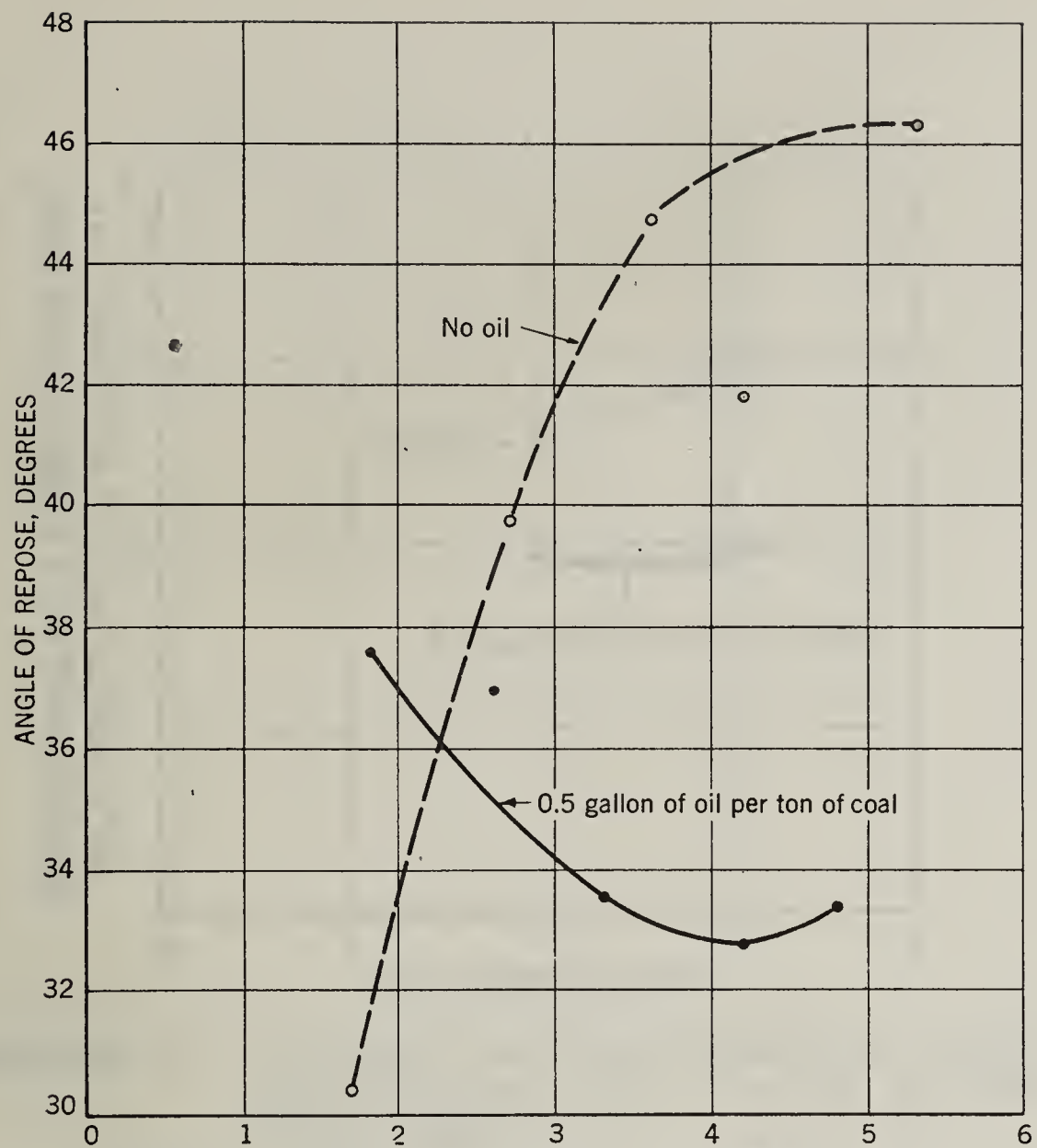


FIGURE 15.- Relation of angle of repose and moisture content of coal C.

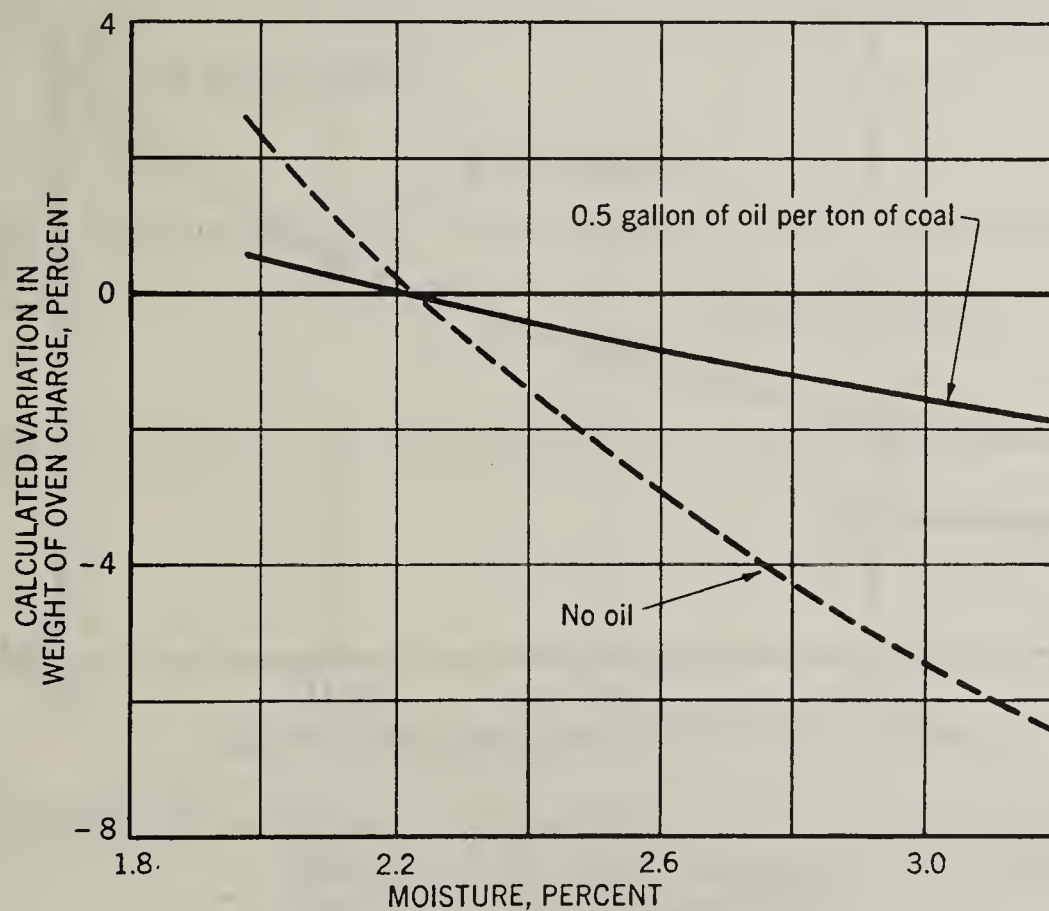


FIGURE 16.- Effect of oil addition on variation in weight of oven charges throughout moisture range at plant C. (Ovens charged by volume.)



Figure 1. Graph of the function $y = \sqrt{x}$ on the interval $[0, 10]$. The function is increasing and concave down.

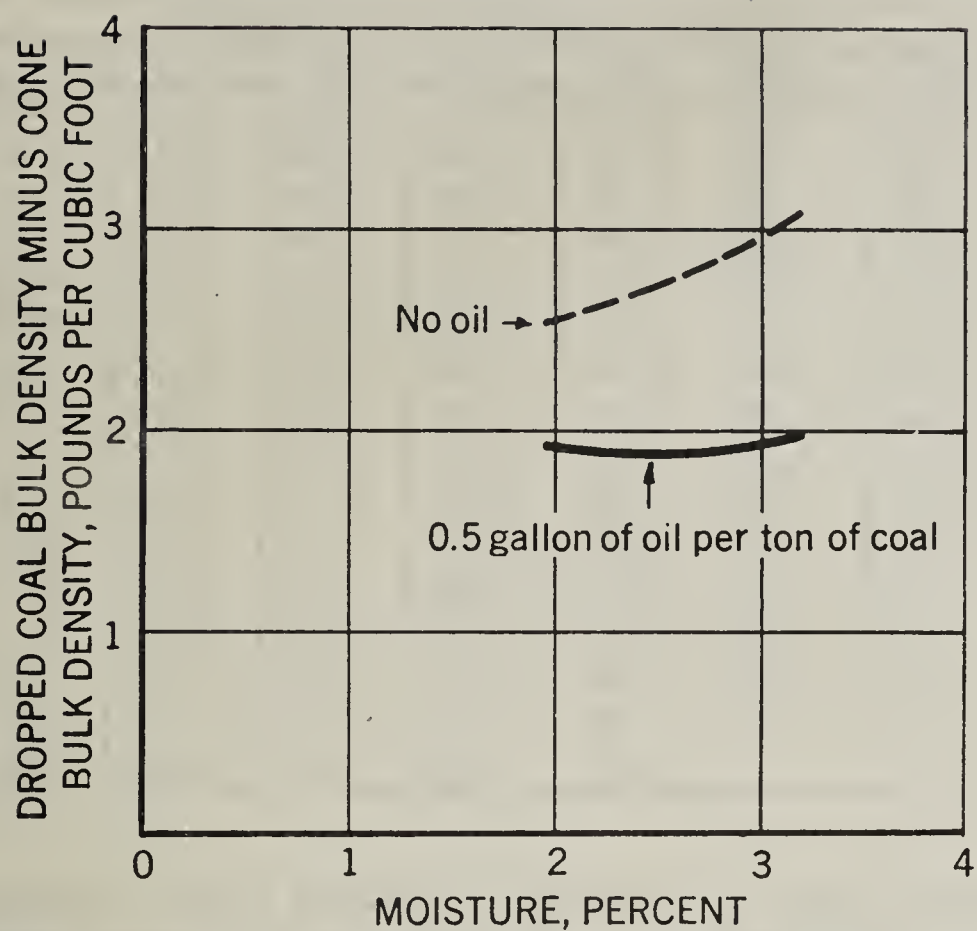


FIGURE 17.- Increase in bulk density of oiled and unoiled coal C caused by dropping coal.

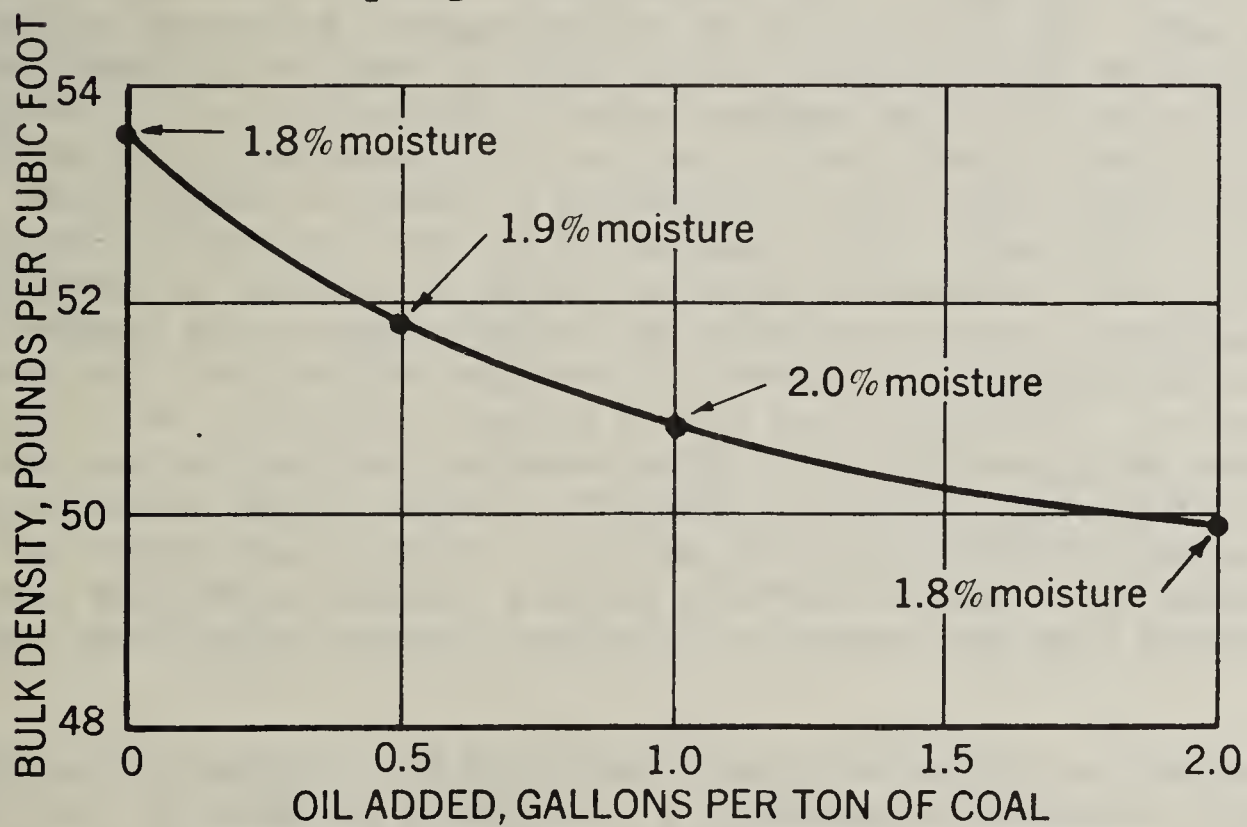


FIGURE 18.- Effect of addition of oil on bulk density of dry samples of coal C. (Dropped-coal method.)



Graph of Temperature (°C) vs. Time (min) for a cooling curve. The curve starts at 100°C, remains constant until 10 minutes, then decreases linearly to 0°C at 40 minutes. The y-axis is labeled 'TEMPERATURE (°C)' and the x-axis is labeled 'TIME (min)'.

Graph of Temperature (°C) vs. Time (min) for a cooling curve. The curve starts at 100°C, remains constant until 10 minutes, then decreases linearly to 0°C at 40 minutes. The y-axis is labeled 'TEMPERATURE (°C)' and the x-axis is labeled 'TIME (min)'.



Graph of Temperature (°C) vs. Time (min) for a heating curve. The curve starts at 0°C, increases linearly to 100°C at 40 minutes, remains constant until 50 minutes, then increases linearly to 150°C at 60 minutes. The y-axis is labeled 'TEMPERATURE (°C)' and the x-axis is labeled 'TIME (min)'.

TABLE 7. - Sieve analyses of test samples of coal C

| Screen size ^{1/} | Cumulative percentage retained | | | | | | | |
|---------------------------|--------------------------------|------|------|------|------|------|------|------|
| | 4 | 6 | 8 | 14 | 35 | 80 | 150 | 200 |
| C-01..... | 10.6 | 18.6 | 25.2 | 44.8 | 73.0 | 87.7 | 93.2 | 95.6 |
| C-02..... | 9.2 | 16.6 | 24.0 | 44.6 | 73.3 | 87.4 | 92.5 | 94.7 |
| C-03..... | 9.8 | 17.8 | 25.6 | 46.4 | 74.1 | 87.9 | 93.2 | 95.4 |
| C-04..... | 10.0 | 18.4 | 26.3 | 47.7 | 74.6 | 88.1 | 93.1 | 95.1 |
| C-05..... | 11.2 | 19.7 | 27.7 | 48.7 | 75.1 | 88.0 | 92.8 | 94.8 |
| C-06..... | 10.2 | 18.1 | 25.8 | 46.4 | 74.1 | 88.6 | 94.3 | |
| C-07..... | 10.0 | 18.0 | 25.8 | 46.7 | 74.2 | 88.6 | 94.1 | 96.7 |
| C-08..... | 10.1 | 17.7 | 25.5 | 46.0 | 73.8 | 88.8 | 94.4 | 97.0 |
| C-09..... | 9.5 | 17.1 | 24.8 | 45.3 | 73.5 | 89.4 | 95.0 | |
| C-10..... | 8.6 | 16.6 | 24.6 | 45.3 | 73.4 | 89.5 | 95.2 | |
| C-11..... | 12.3 | 20.3 | 27.4 | 47.2 | 74.1 | 87.5 | 92.6 | 94.8 |
| C-12..... | 11.1 | 19.3 | 27.5 | 48.2 | 74.9 | 87.9 | 92.6 | 94.8 |
| C-13..... | 11.6 | 19.9 | 27.6 | 47.7 | 74.7 | 88.7 | 94.0 | 96.4 |
| C-14..... | 11.4 | 19.8 | 27.3 | 47.9 | 74.6 | 87.8 | 92.8 | 95.0 |
| C-15..... | 9.6 | 17.0 | 24.1 | 43.4 | 72.7 | 90.7 | 96.5 | |
| C-16..... | 9.7 | 16.8 | 24.1 | 45.1 | 73.2 | | | |

^{1/} Tyler screens.

Figure 16 indicates that a marked improvement in the uniformity of the weight of oven charges should be expected if oil is applied to the coal. When unoiled coal is charged by volume, the weight of an oven charge might vary as much as 6.5 percent from the standard weight of oven charge throughout the moisture range noted at the plant, while the maximum deviation with oiled coal from the operating average should be only 1.9 percent. The calculations indicate that differences as great as 9.2 percent might be noted between the weights of coal of individual ovens charged with unoiled coal C and that the addition of 0.5 gallon of oil per ton of coal should lower this to 2.5 percent. The probable increase in uniformity of the coal charge throughout an oven due to oiling the coal can be estimated from figure 17. In this figure, the differences between the bulk densities measured by the dropped-coal and cone methods are plotted against the moisture content. The maximum difference noted with the unoiled coal was 3.1 pounds per cubic foot, and the maximum noted with the oiled coal was 2.0 pounds per cubic foot. The angle of repose of the unoiled samples increased with increasing moisture content throughout the moisture range studied. The addition of oil raised the angle of repose of the low-moisture sample. It then decreased with increasing moisture content to a maximum at about 4 percent moisture content. No general relationship was established between the angle of repose and bulk density for coal C.

The effect of the addition of different quantities of oil on the bulk density of dry coal is shown in figure 18. A progressive reduction occurred as the quantity of oil added was increased from zero to 2 gallons per ton of coal. This indicates a practical means of reducing the high densities encountered at times at plant C.

TABLE 8. - Bulk densities of test samples of coal C

| Test No. | Moisture, percent | Oil added, gallons per ton ^{1/} | Wetting agent added, percent of moisture content ^{2/} | Bulk density, pounds per cubic foot | | | |
|-----------|-------------------|--|--|-------------------------------------|-----------------------------------|-------------|-----------------------------------|
| | | | | A.S.T.M. method | | Cone method | |
| | | | | As tested | Moisture-free basis ^{3/} | As tested | Moisture-free basis ^{3/} |
| C-01..... | 1.8 | 0 | 0 | 50.0 | 49.1 | 51.0 | 50.1 |
| C-02..... | 2.4 | 0 | 0 | 46.9 | 45.8 | 47.9 | 46.8 |
| C-03..... | 3.4 | 0 | 0 | 42.1 | 40.7 | 43.0 | 41.5 |
| C-04..... | 4.2 | 0 | 0 | 41.0 | 39.3 | 41.4 | 39.7 |
| C-05..... | 5.3 | 0 | 0 | 39.5 | 37.4 | 40.1 | 38.0 |
| C-06..... | 1.9 | 0.5 | 0 | 49.1 | 48.2 | 49.9 | 49.0 |
| C-07..... | 2.4 | 0.5 | 0 | 48.4 | 47.2 | 49.0 | 47.8 |
| C-08..... | 3.3 | 0.5 | 0 | 47.6 | 46.0 | 48.5 | 46.9 |
| C-09..... | 4.3 | 0.5 | 0 | 46.8 | 44.8 | 47.2 | 45.2 |
| C-10..... | 5.1 | 0.5 | 0 | 46.2 | 43.8 | 46.6 | 44.2 |
| C-11..... | 3.4 | 0 | 1 | 42.9 | 41.4 | 43.0 | 41.5 |
| C-12..... | 5.0 | 0 | 1 | 39.4 | 37.4 | 40.1 | 38.1 |
| C-13..... | 3.2 | 0.5 | 1 | 47.6 | 46.1 | 48.5 | 46.9 |
| C-14..... | 4.8 | 0.5 | 1 | 46.0 | 43.8 | 46.5 | 44.3 |
| C-15..... | 2.0 | 1.0 | 0 | 48.2 | 47.2 | 48.5 | 47.5 |
| C-16..... | 1.8 | 2.0 | 0 | 46.9 | 46.1 | 47.0 | 46.2 |

^{1/} Coal spray oil. For properties, see table 2.^{2/} Laboratory aerosol.^{3/} Moisture-free bulk density = as-tested bulk density x $\frac{100 - \text{moisture, percent}}{100}$.

PLANT APPLICATION OF OIL FOR CONTROL OF BULK DENSITY

The following suggestions on the methods of applying oil to control the bulk density of the coal charged to the ovens represent the observations of the authors and the comments of the operators at most of the byproduct-coke plants in this country using oil for this purpose.

The primary equipment required for applying oil to the coal are a storage tank, a pump, and the necessary piping, valves, and fittings. The details, such as pressure-regulating devices, temperature control, feed-control valves, and meter and piping systems, depend upon local conditions and, to some extent, upon the ease and accuracy of control desired.

The size of the storage tank depends upon conditions of delivery of the oil. If the oil is delivered in tank-car lots, the capacity of the storage tank should be such that the car can be unloaded promptly and at the same time have leeway enough to allow for delay in delivery. Where a large amount of oil is used, two storage tanks are desirable, as this will simplify cleaning problems. The storage tank should be insulated and provision made for heating. Steam coils in the tank are probably the simplest if steam is available. If a very large storage tank is used, heating all of the oil in the tank may be avoided by use of a flash heater. If the flash heater is an external one, the suction line should extend into the tank to a point near the center of the bottom of the tank. The temperature to which it is necessary to heat the oil depends upon the viscosity characteristics of the oil used, and ample heating surface should be provided. The tank should be equipped with vent, suction, and filling lines, connection for measuring, steam coils or other means of heating, and a manhole for cleaning. A screen of some sort is advisable if there is a possibility that the oil contains foreign material. The tank should be located with due regard for fire hazards.

All pipe lines should be insulated, and companion steam lines for keeping them hot are desirable. The latter may be omitted, especially if the lines are short, but care would have to be taken that the lines were thoroughly drained when not in use to avoid trouble in starting.

If the circulating line is not too long and is well-insulated the oil can be heated and circulated at such a rate that the loss of heat in the circulating system will not increase the viscosity to the extent that pumping and circulating difficulties will occur. When the viscosity-temperature relationship and the specific heat of the oil are known, a balance between the rate of flow and heat loss can be calculated, and the optimum conditions as to rate of flow and of insulation can be determined.

The type of pump or pumps is not important. A pump for unloading the cars is necessary in many instances.

The oil is best applied to the coal immediately before the final coal crusher. The equipment at the point of application should include a meter, a regulating valve, and a solenoid or some automatic valve arranged so that the oil will be shut off if the belt stops or runs empty. Every precaution

should be taken to prevent spills or dripping of oil onto empty belts. The line running from the regulating valve to the point of delivery to the coal should be short.

There are several different systems for delivery of oil from the storage tank to the point of application. The simplest system consists of a pump equipped with a pressure regulator and a single line to the point of delivery (shown in fig. 19, A). This is not desirable, especially at this time when Bunker C is the only oil that can be purchased for this use as the pressure at the point of delivery will fluctuate and the flow of oil will not be constant because of changes in temperature and viscosity. A more desirable system is one having a return line with a back-pressure regulating valve located near the point of delivery just beyond the offtake to the meter and delivery jet (shown in fig. 19, B). This system may be modified by using a small feed tank located above the point of delivery and having an overflow line returning to the storage tank (shown in fig. 19, C). The pump is operated at a rate high enough to deliver the amount of oil required for the coal plus the excess needed for keeping the pressure constant and the return line in operating condition. A bypass around the pump for draining the system when not in use is desirable.

When the oil is introduced before the crusher it is not necessary to spray or atomize it onto the coal. The oil is allowed to run onto the coal stream through one or more small openings, depending on the width of the coal stream. When small quantities of oil are used, there seems to be no appreciable effect on the rubber in conveyor belts.

Refinements such as temperature control, safety vents, etc., can be added. As the bulk density varies with size of the coal, special care has to be taken with the crushers to obtain uniform crushing, or the bulk density of the oiled coal should be determined frequently and the necessary changes made in the quantity of oil added to maintain uniform bulk density.

SUMMARY AND CONCLUSIONS

One of the problems encountered in the program of the Coke Production Committee and the Bureau of Mines to improve the quality of byproduct coke has been the prevalent lack of control of the bulk density of the coal in the coke ovens. Variations in the moisture content of the incoming coal cause fluctuations in the bulk density of the coke-oven charges and result in the production of nonuniform coke, in unsteady operating conditions, and in possible damage to ovens by occasional excessively high bulk densities. This report shows the results of investigations on samples of coke-oven charges obtained from three byproduct-coke plants experiencing operating difficulties traceable to fluctuations in moisture content of the coal. The methods of bulk-density measurement used in this study are described.

The method of test usually employed in determining the bulk densities of coke-oven charges yields results much lower than the bulk densities of coal in place in the ovens. A method was developed by the Bureau of Mines in which the coal is dropped 6 feet from the hopper of the standard equipment used in

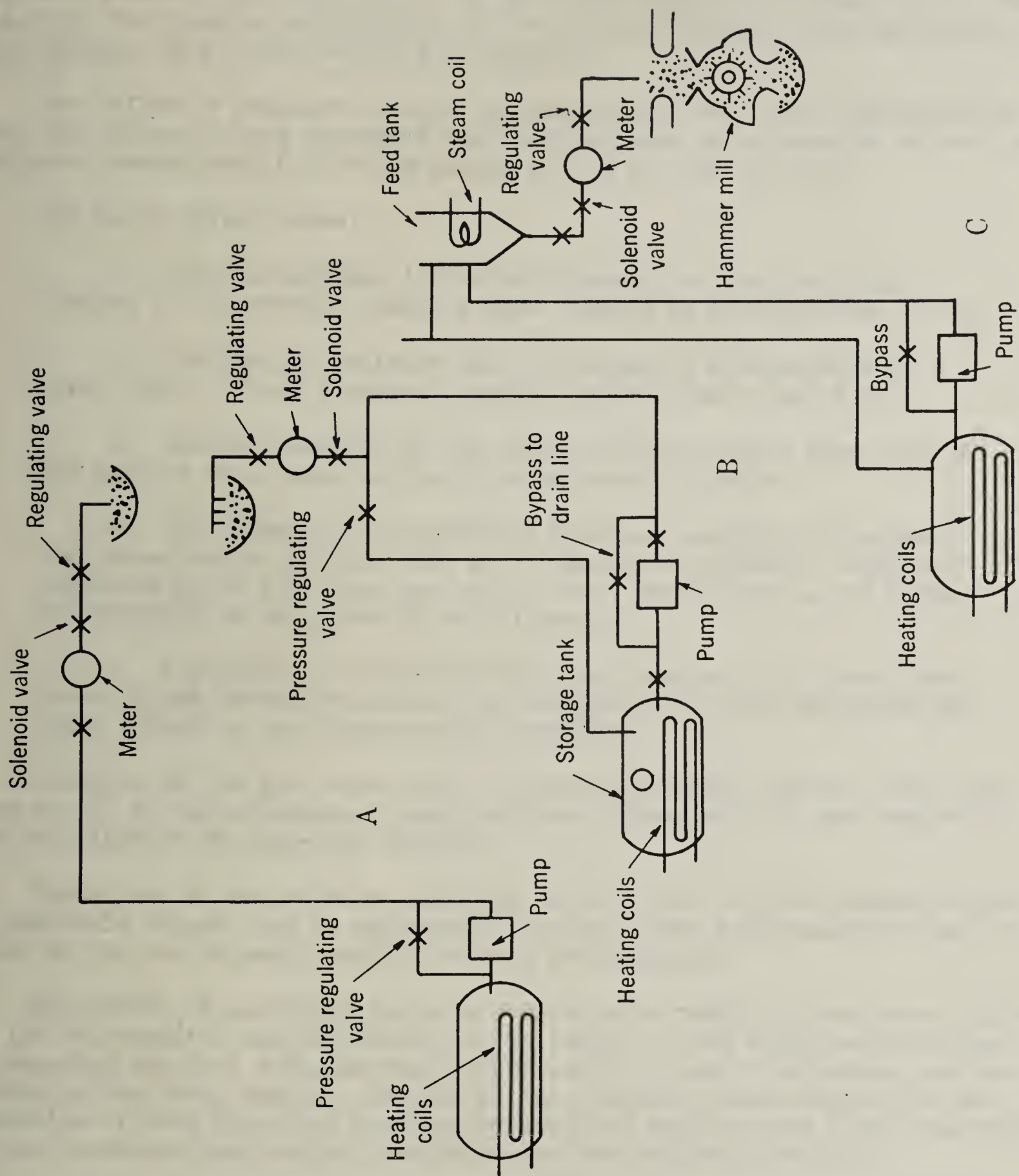
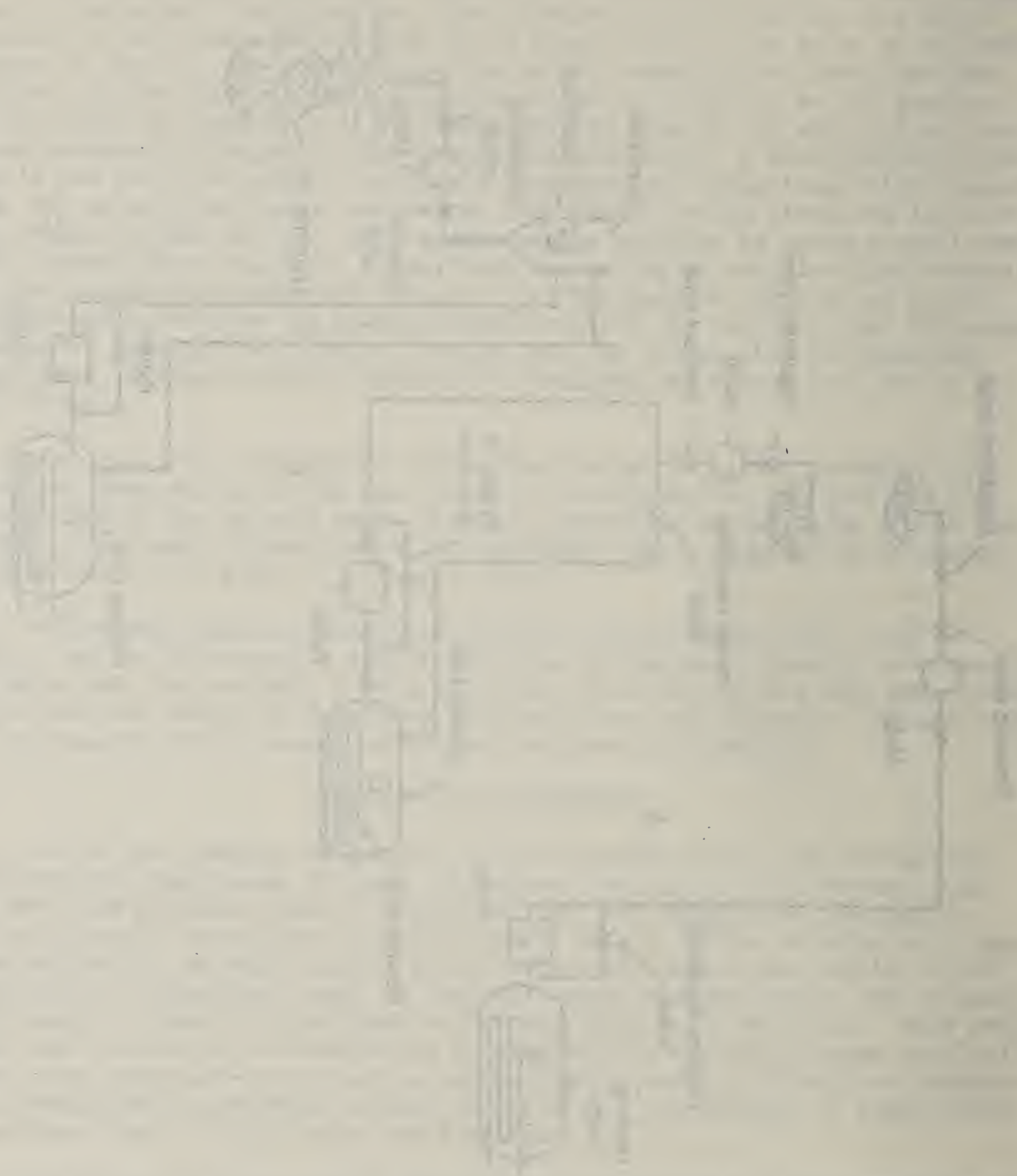


FIGURE 19.- Systems for addition of oil to coal at byproduct- coke plants.



the drop-shatter test for coke into a 2-cubic foot box of specified dimensions. This method, called the dropped-coal method, yields results that agree with the average density of the coal in the ovens calculated from the weight of charge and oven volume. The bulk density of each test sample was determined by the A.S.T.M., the cone (a modification of the A.S.T.M. method), and the dropped-coal methods, and these results are compared.

The effect of moisture content on bulk density was first determined on each lot of coal. This procedure was then repeated after samples of each coal had been treated with 0.2 or 0.5 gallon of oil per ton of coal.

The major effects were:

1. The fluctuations in the bulk density of the coal with changes in the moisture content were reduced by the addition of oil.

2. The results indicate that the range in bulk density in a given coke oven are decreased significantly by addition of oil.

3. The bulk density of the oiled coal was higher than that of the unoiled coal except at very low moisture contents.

4. Oil lowered the excessively high and dangerous bulk densities noted on the unoiled coal at low moisture contents. With oil additions up to 2 gallons per ton of coal, this lowering was roughly proportional to the quantity of oil used.

5. The angles of repose of the oiled samples were lower than those of the corresponding unoiled samples at the same moisture content, except at very low moisture contents.

Analyses of the data were made to show the probable effect of the addition of oil in the solution of plant problems concerned with the control of the bulk density of coke-oven charges.

Tests made at two moisture contents on oiled and unoiled samples of one of the coals showed that no appreciable change in the bulk densities was produced by the use of small quantities of a wetting agent.

The effect of modifying the size consist of a sample of coke-oven charge on its bulk density was determined on one sample. This sample was modified by removing the plus 3/8-inch coal, crushing it to pass this screen, and recombining the total sample. Throughout the moisture range studied the bulk densities of both the oiled and unoiled modified samples were lower than those of the corresponding original sample at the same moisture content.

An outline is presented of some of the methods now being used in the industry to apply oil to the coal charged to the ovens.

It must be emphasized that oil should not be applied indiscriminately to coal going to coke ovens. Tests should be made on the particular coal or blend of coals actually being charged at a given plant and a careful study made of operating conditions and problems at the plant. In some instances, the increased bulk density resulting from the use of oil may develop dangerously high expansion pressures in the ovens, resulting in pushing difficulties or damage to the oven walls.

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REPORT OF INVESTIGATIONS

UTILIZATION OF ANTHRACITE FINES IN THE MANUFACTURE OF BYPRODUCT COKE



BY

WILLIAM SEYMOUR AND L. D. SCHMIDT

REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

UTILIZATION OF ANTHRACITE FINES IN THE MANUFACTURE OF BYPRODUCT COKE^{1/}

By William Seymour^{2/} and L. D. Schmidt^{3/}

FOREWORD

Among the many problems created by World War II, the question of supplies and distribution of raw materials is of outstanding importance. One of the most critical of these raw materials is fuel, and of the fuels coal is of primary importance. The normal consumption of coal has increased greatly owing to the increased tempo of industry in general. It has been necessary to divert much of the fuel oil, gasoline, etc., ordinarily used for industrial and domestic purposes, to supply the enormous demands of mechanized warfare. Coal must be provided to replace this fuel. Furthermore, the enormous increase in the production of steel has increased the demand for coking coals to a critical point.

The Solid Fuels Administration for War is encouraging the use of anthracite fines in the production of byproduct coke for blast furnaces for three reasons. First, the production of anthracite for domestic use is hampered by the inability to find a market for the fines incidental to the production of domestic sizes. Second, the shortage of low-volatile coking coal is acute, and any action that will decrease the quantity of low-volatile coal required will relieve the situation. As will be seen in this report, there is some promise that use of anthracite fines in coke-oven mixes will lower the amounts of low-volatile coal required. Third, utilization of these anthracite fines will tend also to alleviate the general fuel shortage. It has been the privilege of the Bureau of Mines to cooperate with the Solid Fuels Administration in the technical problems involved.

This paper is a preliminary report upon the utilization of anthracite fines in byproduct coke.

A. C. Fieldner
Chief, Fuels and Explosives Branch

^{1/} The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3808."

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INTRODUCTION AND SUMMARY

This report is of a preliminary nature. It is presented at this time because prompt action is necessary to relieve the fuel shortage. The production of domestic sizes of anthracite is hampered by the inability to dispose of the fines produced in the preparation of domestic sizes, and there is a shortage of low-volatile coal for use in the manufacture of byproduct coke. Replacing 3 to 5 percent of Pocahontas coal with the same proportion of anthracite fines in the coal mixtures used in the manufacture of byproduct coke will alleviate both of these conditions.

This investigation has revealed that at some plants anthracite fines are now being used in the coking mixtures used for blast-furnace coke and that their blast-furnace practice with this coke is satisfactory. At many additional plants preliminary tests have been made, and study of the results indicates that plant-scale tests would show that anthracite fines can be used at many of these plants without any marked effect on blast-furnace practice.

ACKNOWLEDGMENTS

The authors are deeply indebted to H. M. Chapman of the Office of Solid Fuels Administration for much of the data on plant results. Thanks are also due to A. C. Fieldner of the Bureau of Mines whose active interest made this work possible. Many officials and operators of byproduct-coke plants gave generously their time and the results of their investigations. The carbonization tests at the Bureau of Mines were supervised by J. D. Davis.

REVIEW

The effect on the coke produced of the admixture of inert material to coking coal has been the subject of many investigations. One outstanding report of such investigations is given in the report of the Gas Production Committee of the American Gas Association, 1936^{4/} and 1937.^{5/}

The reference to this work is made because many operators believe that the action of anthracite fines in the coking mixture is similar to that of breeze. All of the tests made in these investigations were on a plant scale and under regular operating conditions. They show that certain sizes and amounts of coke breeze may be added to certain kinds of either blended or 100 percent high-volatile coal; that the limit of top size of breeze that may be added advantageously is minus 1/8-inch; and that the limit of amount is 4 percent of minus 1/32-inch, 3 percent of minus 1/16-inch, and 2 percent of minus 1/8-inch. In this report it is stated that "It will be observed that the coke made from 100 percent high volatile coal seems to be affected in much the same manner as that produced from blended coals, but the increase in size is not so great"; also that tumbler tests show that breeze in amounts up to 5 percent of the coal may be added with very little effect on the strength of the coke produced providing the size of the breeze does not exceed 1/32-inch. Only slight weakening of the coke was noted when the breeze added did not exceed 3 percent of minus 1/16-inch size.

4/ Pfluke, F. J., Coke Strength and Structure as Affected by Coke Breeze Admixture to Coal: Proc. Am. Gas Assoc., 1936, pp. 771-777.

Sedlachek, A. C., Philadelphia Coke Company Test Results Using 80 Percent High-Volatile Powellton and 20 Percent Low-Volatile Pocahontas Coal Mixtures with Coke Breeze Added: Proc. Am. Gas Assoc., 1936, pp. 779-785.

Pfluke, F. J., Rochester Gas & Electric Corporation Test Results Using 100 Percent High-Volatile Pittsburgh Washed Coal with Coke Breeze Added: Proc. Am. Gas Assoc., 1936, pp. 786-790.

Huyck, A. B., Investigation of Effects of the Coke Size and Strength of Adding Breeze to Regular Coke Mixture: Proc. Am. Gas Assoc., 1936, pp. 790-792.

5/ Pfluke, F. J., Crushed Coke Size as Affected by Coke-Breeze Admixture to Coal Prior to Carbonization: Proc. Am. Gas Assoc., 1937, pp. 619-631.

Sedlachek, A. C., Philadelphia Coke Company Test Results Using 80 Percent High-Volatile Powellton and 20 Percent Low-Volatile Pocahontas Coal Mixtures with Coke Breeze Added: Proc. Am. Gas Assoc., 1937, pp. 631-643.

Pfluke, F. J., Rochester Gas & Electric Corporation Test Results Using 100 Percent High-Volatile Pittsburgh Washed Coal with Coke Breeze Added: Proc. Am. Gas Assoc., 1937, pp. 643-648.

In recent years the addition of small amounts (3 to 6 percent) of anthracite fines or finely pulverized coke breeze to the coking mixtures used in the manufacture of foundry coke has become quite common practice. A comprehensive report upon the use of anthracite for this purpose has been published by I. M. Roberts.^{6/} Roberts' experience is that anthracite fines give better results than coke breeze.

Search of the literature fails to reveal any exhaustive tests on the effect of additions of fine anthracite to various blends of coking coals. However, the subject is not a new one. In the last 25 years several companies chiefly in the Eastern district where the location is such that fine anthracite can be delivered to the plant at a lower cost than coking coals, have made more or less complete tests upon the use of anthracite. The results of these tests have been such that the use of anthracite did not appear to be economically feasible for the plants concerned. Probably the chief reason why this was so is that the use for many years of the excellent, high-grade coke made from the best coking coals has established a technique in blast-furnace and other industrial practice that is not easily changed. Also, the scope of the tests was not sufficient to obtain full information as to the effect of the many variables, such as various percentages of the coals used and the coking time, upon the quality of the coke produced.

Recent experience in western plants with the use of the lower-rank coals of Colorado has demonstrated that coke with comparatively low physical test values can be used successfully in the blast furnace; also, some plants in the central and eastern districts are getting good results on their blast furnaces with coke having fairly low tumbler stability and hardness values.

DETAILED REPORT OF TESTS AND OPERATIONS AT BYPRODUCT-COKE PLANTS

Several companies have made or are making preliminary tests on blends containing anthracite fines. The results of the tests that have been made available to the authors show wide variations. Some tests have been rather elementary and a few fairly comprehensive, including test runs of the anthracite coke in the blast furnace.

Complete data regarding actual plant tests are difficult to obtain; in some cases the plants do not make all the standard tests for coke. In others, owing to the variety of coals used and changing conditions, the operators feel that individual tests are not reliable and that the average of tests covering a considerable length of time will be necessary to provide conclusive results.

Table 1 summarizes the experience at 21 byproduct-coke plants on the use of anthracite fines.

^{6/} Roberts, I. M., Increasing the Percentage Production of Large Size Coke at Fast Coking Rates: Am. Inst. Min. and Met. Eng. Tech. Paper 1612, September 1942, 11 pages.

TABLE 1. - Tabulation of plants using anthracite fines and of plant tests

| Plant | Normal mix | | | Anthracite mix | | | Type of coke produced | Length of time used, or tonnage made during test | Results and remarks |
|-------|--------------------|-------------------------|--|-------------------------|-----------------------|----------------------------|-------------------------|--|---------------------|
| | High tile, percent | Low vola- tile, percent | High vola- tile, percent | Low vola- tile, percent | Anthra- cite, percent | Blast furnace | | | |
| A * | 75 | 25 | 79 | 15 | 6 | Blast furnace | 10 months* | Blast-furnace production maintained. Details in text. | |
| B * | 90 | 10 | 91 | 4 | 5 | do. | 5 months* | Blast-furnace performance good. See text. | |
| C * | 73 | 27 | 4 percent low volatile replaced with 4 percent anthracite. | | | do. | 5 months* | Apparently satisfactory in blast furnace. See text. | |
| D ° | 50 | 50 | 50 | 44 | 6 | Foundry and domestic | 1-1/2 yr. ° | Increased production of foundry coke. Special test made on anthracite in domestic mix. See text. | |
| E | 80 | 20 | See text | | | Domestic | 4 ovens (about 50 tons) | Tests made with anthracite in mix as reported in text. | |
| F | 75 | 25 | do. | | | Blast furnace | Oven-scale test | Results inconclusive; more tests desirable. | |
| G * | 66 | 34 | Mix not given | | | Blast furnace and domestic | 7 months* | Use 2 percent in winter months. More in summer. | |
| H ° | 74 | 26 | Not given | | | Foundry and blast furnace | Several years ° | Anthracite used in foundry mix. Larger size and higher shatter values. | |

* Plants now using anthracite in regular production of blast-furnace coke.

° Plants now using anthracite in regular production of foundry coke.

TABLE 1. - Tabulation of plants using anthracite fines and of plant tests (Cont'd.)

| Plant | Normal mix | | | Anthracite mix | | | Type of coke produced | Length of time used, or tonnage made during test | Results and remarks |
|-------|--------------------------|-------------------------|--|-------------------------|--------------------------|-------------------------------------|-------------------------------------|--|---|
| | High vola- tile. percent | Low vola- tile. percent | High vola- tile. percent | Low vola- tile. percent | High vola- tile. percent | Low vola- tile. percent | | | |
| I | 75 | 25 | 75 | 20 | 5 | Foundry and domestic | Foundry and domestic | Several hundred tons | Plant-scale tests being made; complete report not available. |
| J | 70 | 30 | Test's made with 5 and 10 percent anthracite | | 10 | Furnace | Furnace | Oven-scale tests | Yield of furnace coke less due to crushing larger size coke. Preferred to use 75 high-volatile, 25 low-volatile mix. Their experience indicates that 90-7-3 mixture will produce a satisfactory coke. |
| K | 85 | 15 | 96.5 | 0 | 3.5 | do. | do. | Not known | Increased production of foundry coke; used in foundry mix only. |
| L | 60 | 40** | 60 | 35 | 5** | Foundry, blast furnace and domestic | Foundry, blast furnace and domestic | 2-1/2 years | Tried anthracite in mix. Results on blast furnace very poor. Quality of their coking coal is below average. Anthracite fines used in foundry mix. |
| M | 85-82 | 15-18 | | Not given | | Blast furnace | Blast furnace | Not given | Tests of 2 days' duration gave poor results on blast furnace. Oven-scale tests made afterward. See text. Have made some tests with varying results. Are continuing tests. |
| N | 70 | 30 | | do. | | Foundry and blast furnace | Foundry and blast furnace | do. | |
| O | 86 | 14 | 86 | 10 | 4 | Blast furnace | Blast furnace | About 3,000 tons made | |
| P | Various | | | | 5 | do. | do. | | |

See footnotes on page 6.

** Foundry mix.

TABIE 1. - Tabulation of plants using anthracite fines and of plant tests (Cont'd.)

[illegible]

Plant A

The operators of this plant made some tests of coal mixtures containing anthracite fines in the fall of 1943 and for about 1 month made about half of their blast-furnace coke from a mixture of 95 percent high-volatile coal and 5 percent anthracite (Buckwheat No. 4). The use of 50 percent of this coke in their blast furnaces did not cause trouble.

Later, more extensive tests were made with various mixtures and at different coking times. The results of all of the tests are tabulated in table 2. It is apparent that the size of the coke and the shatter-test values increase with increase in the percentage of anthracite fines. Reducing the coking time reduced the size and the shatter-test values.

At present a mixture of 79 percent high-volatile coal, 15 percent low-volatile coal, and 6 percent anthracite fines with a coking time of 16 hours and 16 minutes is being used for all the coke produced. This mixture has produced enough coke over 4-inch for the foundry and the required tonnage of 1-1/2 to 3-inch coke for the blast furnaces. The throughput has increased about 5 percent and the breeze production about 1 percent.

Plant B

The operators of this plant had been using a mixture of 90 percent high-volatile coal (Pittsburgh bed) and 10 percent low-volatile coal (West Virginia) and are now using a mixture of 91 percent high-volatile, 4 percent low-volatile, and 5 percent anthracite. They have used this mixture long enough to justify conclusions and are well-satisfied with results in the blast furnace. They report an increase in screen test (on 2-inch), increase in shatter (on 2-inch), and a slight decrease in the tumbler values.

Plant C

The operators of this plant, which produces a large amount of blast-furnace coke, have replaced 4 percent Pocahontas with 4 percent anthracite fines and report that the porosity has dropped slightly, the coke size has increased, and the small coke and breeze remained about the same. The tumbler (Curran-drum) results have remained about the same. The coke is apparently satisfactory in the blast furnaces. The operators of this plant recommend that the anthracite have less than 13 percent ash and have a large proportion smaller than 20-mesh.

Plant D

The operators of this plant regularly use 6 percent anthracite fines in their foundry mix. Early in 1944 they made a fairly comprehensive study of the effect of the addition of anthracite fines to their domestic coke-oven blend. The tests were made on an oven-scale basis. The results are shown in table 3.

TABLE 2. - Results of tests of coal mixtures containing anthracite fines (plant A)

Preliminary tests (coking time, 16 hours, 48 minutes):

| Coal mixture | 1 | 2 | 3 | 4 |
|-------------------------------|------|------|------|-------|
| High volatile percent | 75 | 75 | 80 | 95 |
| Low volatile do. | 25 | 20 | 15 | 0 |
| Anthracite do. | 0 | 5 | 5 | 5 |
| Run-of-oven coke: | | | | |
| On 3-1/2 inch sieve do. | 28.0 | 55.6 | 45.1 | 26-30 |
| On 3-inch sieve do. | 49.0 | 72.2 | 60.8 | 45-50 |
| Shatter test (2-inch) | 74.2 | 89.0 | 84.0 | |

Final tests (coking time, 16 hours, 48 minutes):

| Coal mixture | 1 | 2 | 3 | 4 | 5 | 6 standard mix |
|-----------------------------|------|------|------|------|------|----------------|
| High volatile percent | 95 | 80 | 79 | 78 | 77 | 75 |
| Low volatile do. | 0 | 18 | 18 | 18 | 18 | 25 |
| Anthracite do. | 5 | 2 | 3 | 4 | 5 | 0 |
| Run-of-oven coke: | | | | | | |
| On 3-1/2-inch sieve ... do. | 27.1 | 31.5 | 31.9 | 36.6 | 41.9 | 28.0 |
| On 3-inch sieve do. | 45.1 | 49.9 | 49.4 | 54.0 | 61.3 | 49.0 |
| Shatter test (2-inch) ... | 73.9 | 77.9 | 76.9 | 80.9 | 82.1 | 74.2 |
| Cell space percent | 45.8 | 50.4 | 50.5 | 49.4 | 48.2 | 51.1 |

Coking time 16 hours , 16 minutes:

| Coal mixture | 1 | 2 | 3 | 4 |
|-----------------------------|------|------|------|------|
| High volatile percent | 75 | 77 | 80 | 79 |
| Low volatile do. | 25 | 18 | 15 | 15 |
| Anthracite do. | 0 | 5 | 5 | 6 |
| Run-of-oven coke: | | | | |
| On 3-1/2 inch do. | 30.4 | 36.3 | 38.3 | 37.7 |
| On 3-inch do. | 50.3 | 54.0 | 57.7 | 54.9 |
| Shatter test (2-inch) | 74.9 | 81.0 | 78.9 | 77.2 |
| Cell space percent | - | - | 48.9 | 46.9 |

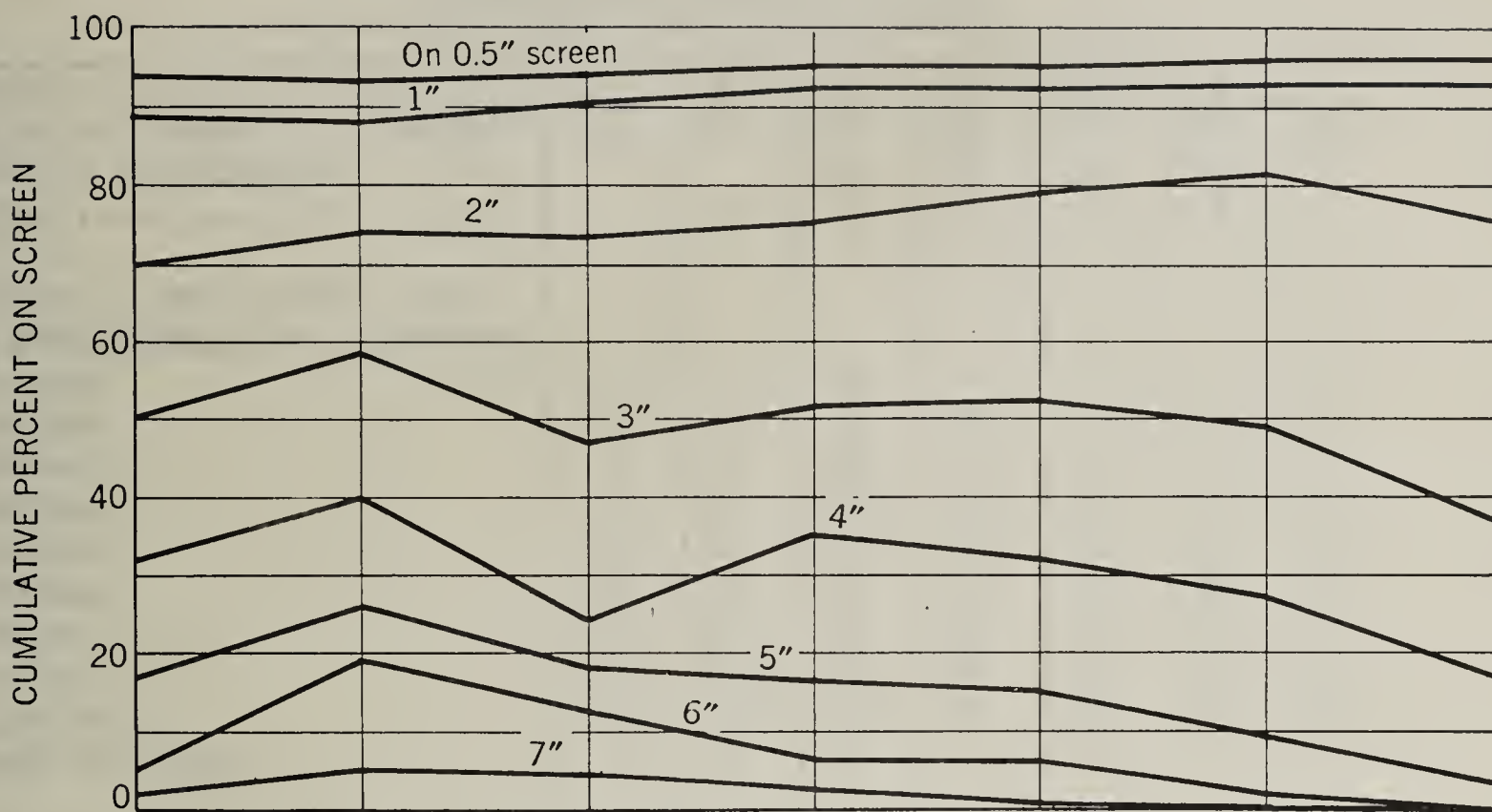


Figure 1.—Cumulative screen analysis, showing effect of addition of anthracite fines to coking mixtures, commercial plant D.

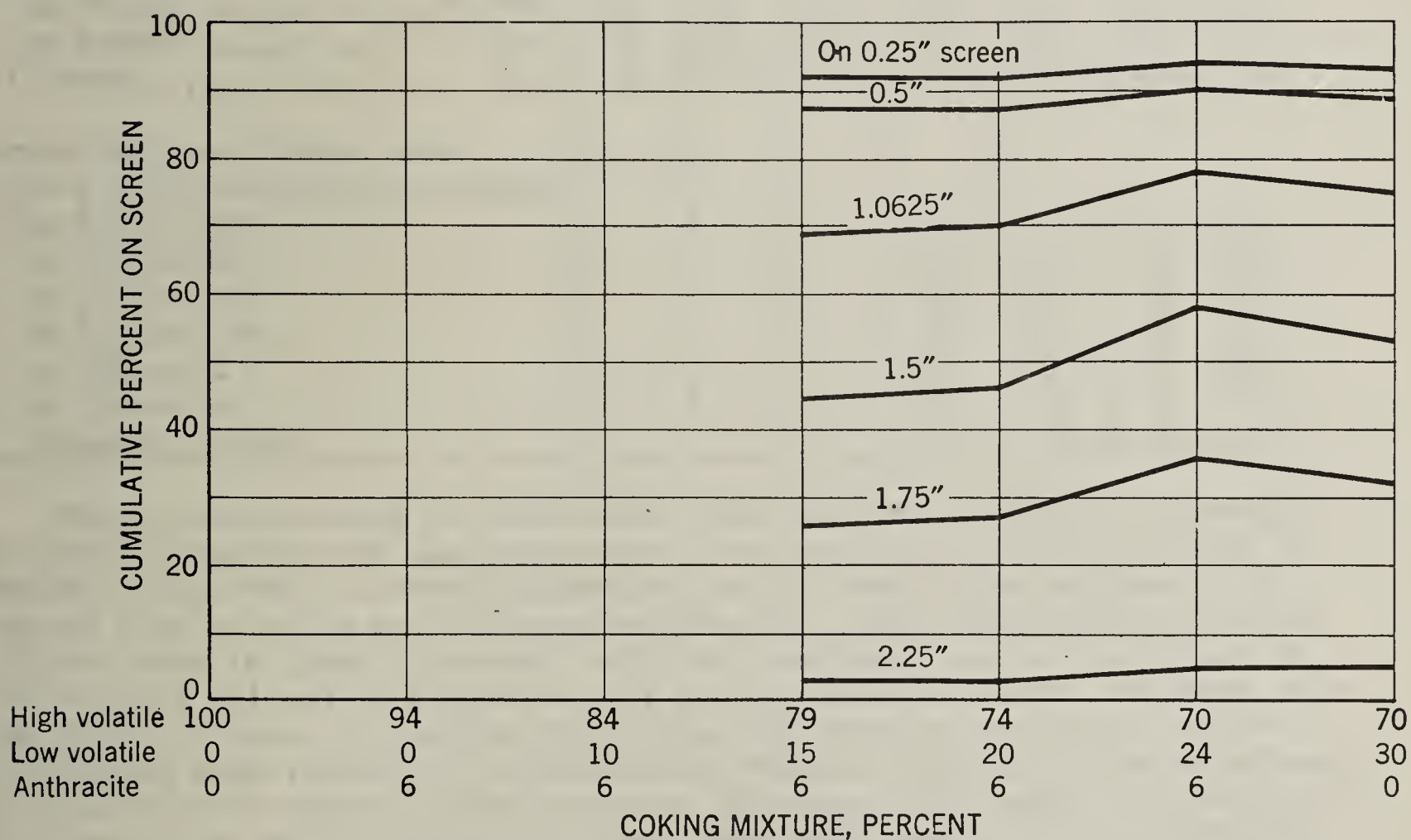


Figure 2.—Cumulative screen analysis of crushed coke, showing effect of addition of anthracite fines to coking mixtures, commercial plant D.



(a) and (b) show the results of the numerical solution of the system of equations (1) and (2) for different initial conditions. The curves represent the time evolution of the variables x and y .

TABLE 3. - Effect of addition of anthracite fines upon properties of coke (plant D)

| Test number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|-----------------------------------|------|------|------|------|------|------|------|
| High volatile (Eagle)percent | 100 | 94 | 84 | 79 | 74 | 70 | 70 |
| Low volatile (Pocahontas). do. | | | 10 | 15 | 20 | 24 | 30 |
| Anthracite do. | | 6 | 6 | 6 | 6 | 6 | |
| Screen test on run-of-oven coke: | | | | | | | |
| Square mesh, cumulative ..percent | | | | | | | |
| On 8-inch | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| On 7-inch | 2 | 5 | 4 | 2 | 0 | 0 | 0 |
| On 6-inch | 5 | 19 | 12 | 6 | 6 | 1 | 0 |
| On 5-inch | 17 | 26 | 18 | 16 | 15 | 9 | 3 |
| On 4-inch | 32 | 40 | 24 | 35 | 32 | 27 | 17 |
| On 3-inch | 50 | 58 | 47 | 51 | 52 | 49 | 37 |
| On 2-inch | 70 | 74 | 73 | 75 | 79 | 81 | 76 |
| On 1-inch | 89 | 88 | 90 | 92 | 92 | 93 | 93 |
| On 1/2-inch | 94 | 93 | 94 | 95 | 95 | 96 | 96 |
| Through 1/2-inch | 6 | 7 | 6 | 5 | 5 | 4 | 4 |
| Shatter test: | | | | | | | |
| Full-length pieces | | | | | | | |
| On 3-inchpercent | 25 | 37 | 27 | 21 | 64 | 53 | 49 |
| On 2-inch do. | 45 | 58 | 62 | 62 | 81 | 78 | 77 |
| Cell space do. | 37.9 | 37.1 | 41.4 | 44.5 | 46.8 | 49.2 | 52.3 |
| Screen test on crushed coke: | | | | | | | |
| Square mesh, cumulative..percent | | | | | | | |
| On 2-1/4-inch | | | | 3 | 3 | 5 | 5 |
| On 1-3/4-inch | | | | 26 | 27 | 36 | 32 |
| On 1-1/2-inch | | | | 45 | 46 | 58 | 53 |
| On 1-1/16-inch | | | | 69 | 70 | 78 | 75 |
| On 1/2-inch | | | | 87 | 87 | 90 | 89 |
| On 1/4-inch | | | | 92 | 92 | 94 | 93 |
| Through 1/4-inch | | | | 8 | 8 | 6 | 7 |

The screen analyses of run-of-oven coke have been plotted in figure 1. The general tendency of the anthracite to increase the size of the coke is obvious. This effect is most pronounced in the case of the mixture of 94 percent high volatile and 6 percent anthracite. Also, the percent of minus 1/2-inch coke is high (7 percent) with this mixture. As the percentage of low volatile (mixed) is increased, the average size decreases, but even with the 70-24-6 mixture it remains higher than the mixture without anthracite (70 percent high volatile, 30 percent low volatile (mixed)). The percentage of minus 1/2-inch shows a fairly uniform decrease. The tests with less than 15 percent low volatile (mixed) did not make good coke; it was too finery and broke up badly. Crushing tests were made upon the coke from mixtures containing 15 percent and higher percentages of low volatile (mixed). These are shown graphically in figure 2. It is indicated that the addition of anthracite in these cases had little effect on the quantity of small coke

or breeze (minus 1/4-inch) produced in the crushing of the coke. In fact, the breeze produced in the crushing of the coke from the 70-24-6 mixture was less (1 percent) than that from the 70-30 mixture.

Plant E

The operators of this plant, who are engaged chiefly in the manufacture of domestic coke and gas, made a thorough test of blends of anthracite with their standard coking coals. The details of these tests are given in table 4. The screen analyses on the run of oven coke are plotted in figure 3 and the screen analyses after crushing (double crushing) in figure 4. Again as in the previous test, the addition of anthracite caused an increase in the size of the coke (fig. 3). However, in this case, as shown in figure 4, the increase in breeze (minus 1/2-inch) after crushing remains high even with the 85-10-5 mixture. These operators crush a large percentage of their coke to produce domestic sizes; therefore, this increase in breeze is an important item. The tests indicate that the percentage of breeze produced when crushing increased from 8.6 percent with no anthracite to 11.2 percent, a net increase of 2.6 percent, even when the optimum mixture containing 5 percent anthracite was used (80-15-5). An additional factor against the use of anthracite in this plant was the decreased yield of gas, which is an important item in their operation.

The shatter- and tumbler-test results are plotted in figure 5. The shatter tests show higher values when the anthracite is added, and the tumbler tests show lower hardness and stability.

Plant F

The operators of this plant, where the chief product is blast-furnace coke, have made a series of tests on a large oven-scale basis (11 to 15 ovens) but did not make enough coke to obtain reliable information as to the effect on the blast furnaces. In one of their tests using 5 percent anthracite fines the furnace blast pressure went up when the anthracite coke was used. In the second test no change was noticed. The detailed results of these tests are tabulated in table 5 and the screen tests and tumbler tests have been plotted in figures 6 and 7. The physical tests show that the addition of 5 percent anthracite caused only small changes in screen and tumbler results. The test in which 5 percent breeze was used indicates that the resulting coke is not as good as that produced from the same percentage of anthracite fines.

Plant G

All of the coal used at this plant is delivered during the season of navigation on the Great Lakes, and the amount necessary for the winter months is carried in stock. As there is a certain amount of oxidation of the stored coal and consequently some deterioration in coking property, only 2 percent anthracite fines can be used with this coal. When freshly mined coal is used the percentage of anthracite can be increased.

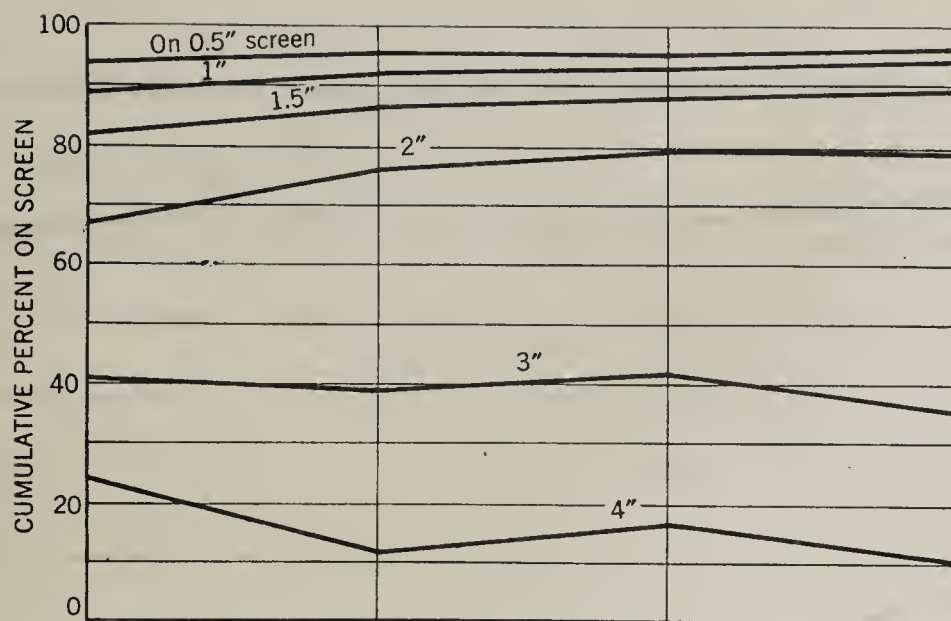


Figure 3.—Cumulative screen analysis, showing effect of addition of anthracite fines to coking mixtures, commercial plant E.

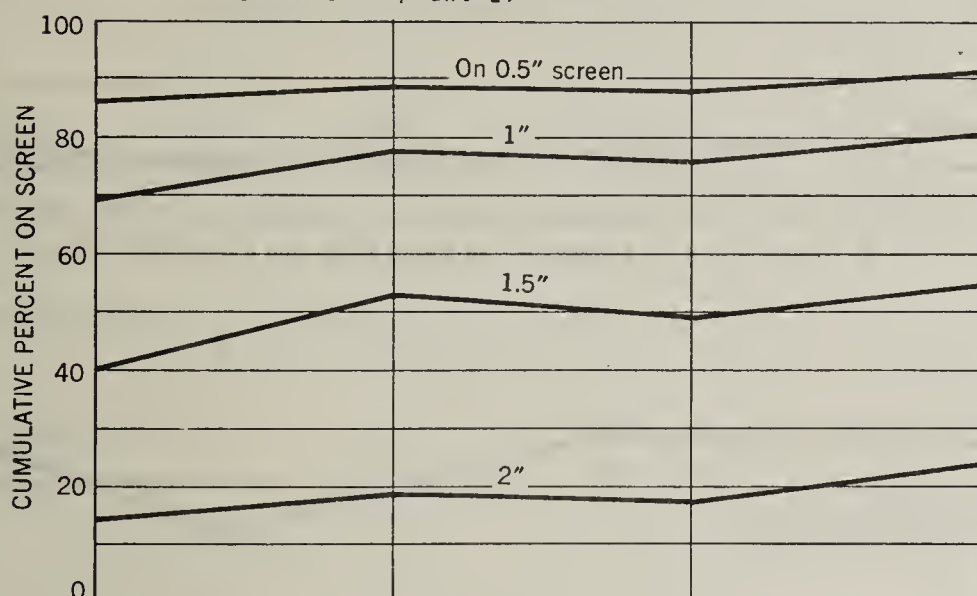


Figure 4.—Cumulative screen analysis, double-crushed coke, showing effect of addition of anthracite fines to coking mixtures, commercial plant E.

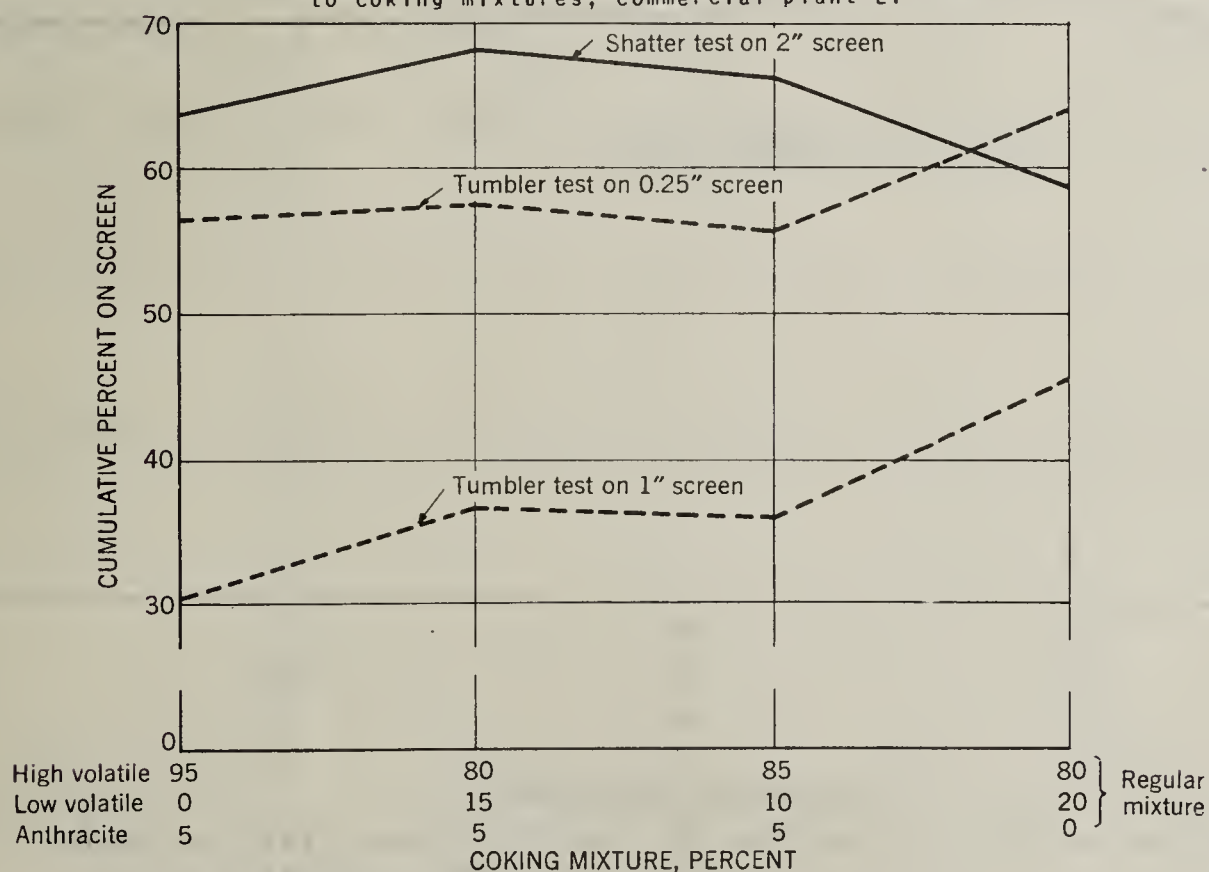
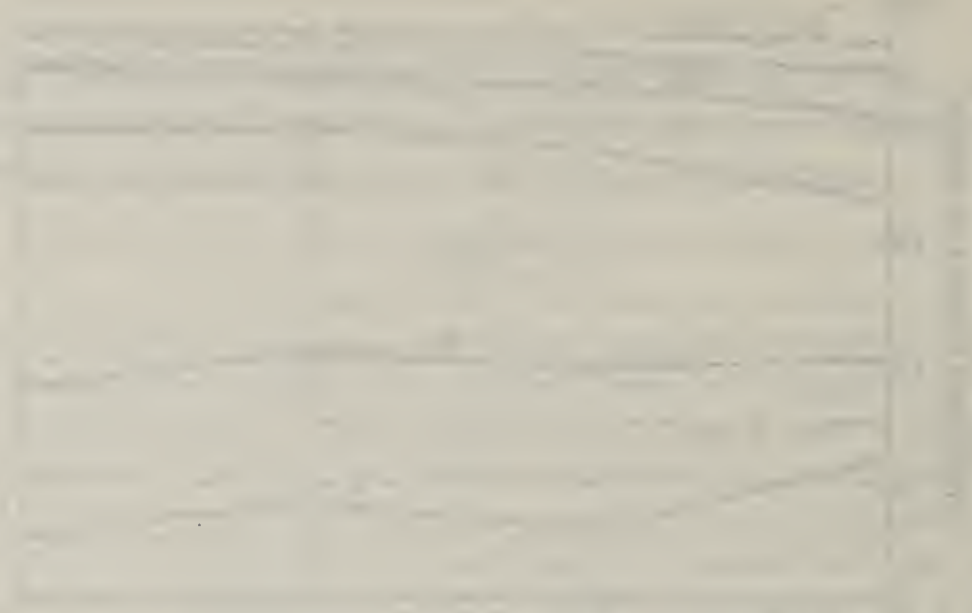


Figure 5.—Shatter and tumbler tests, showing effect of addition of anthracite fines to coking mixtures, commercial plant E.



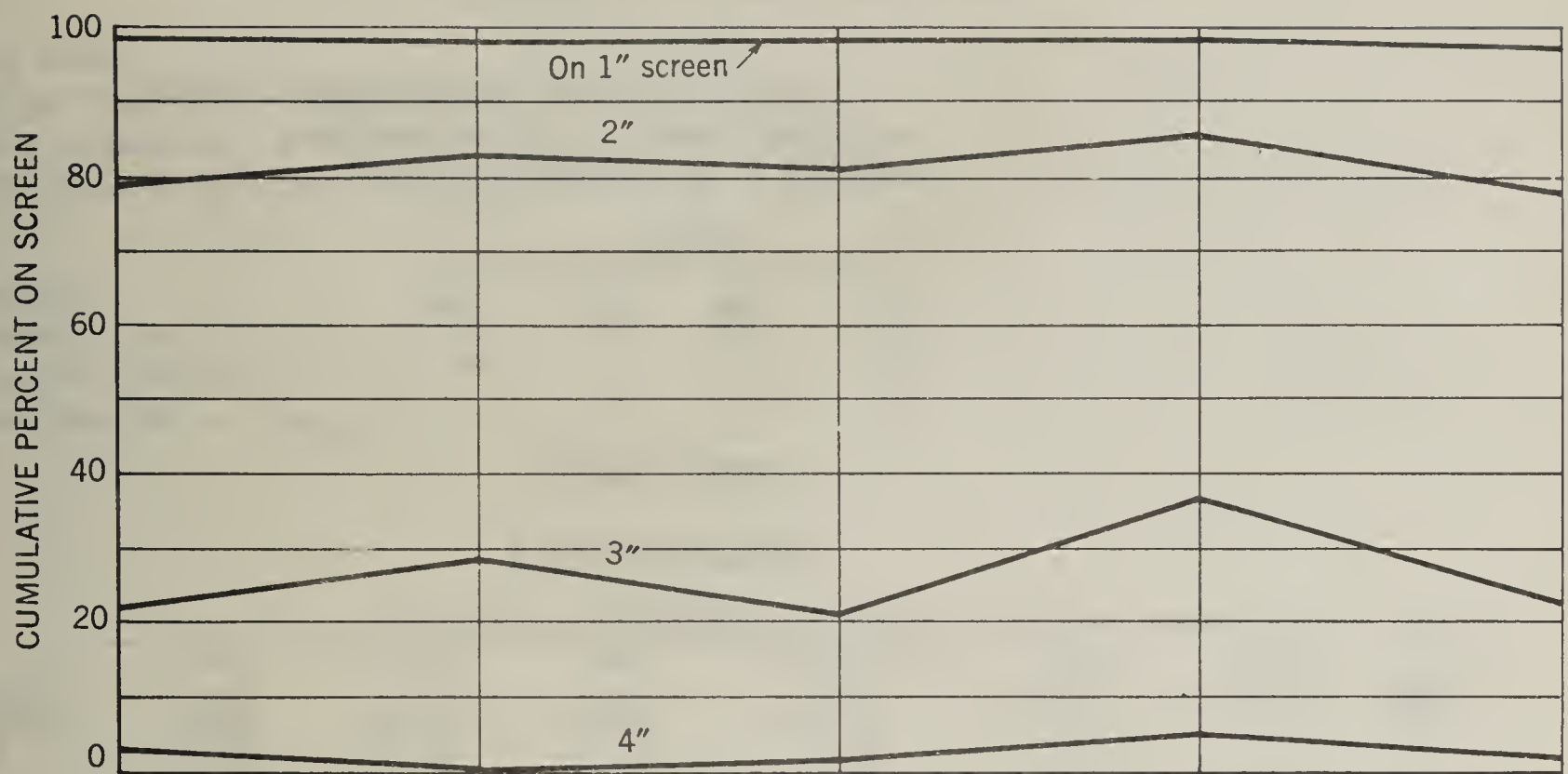


Figure 6.—Cumulative screen analysis, showing effect of addition of anthracite fines to coking mixtures, commercial plant F.

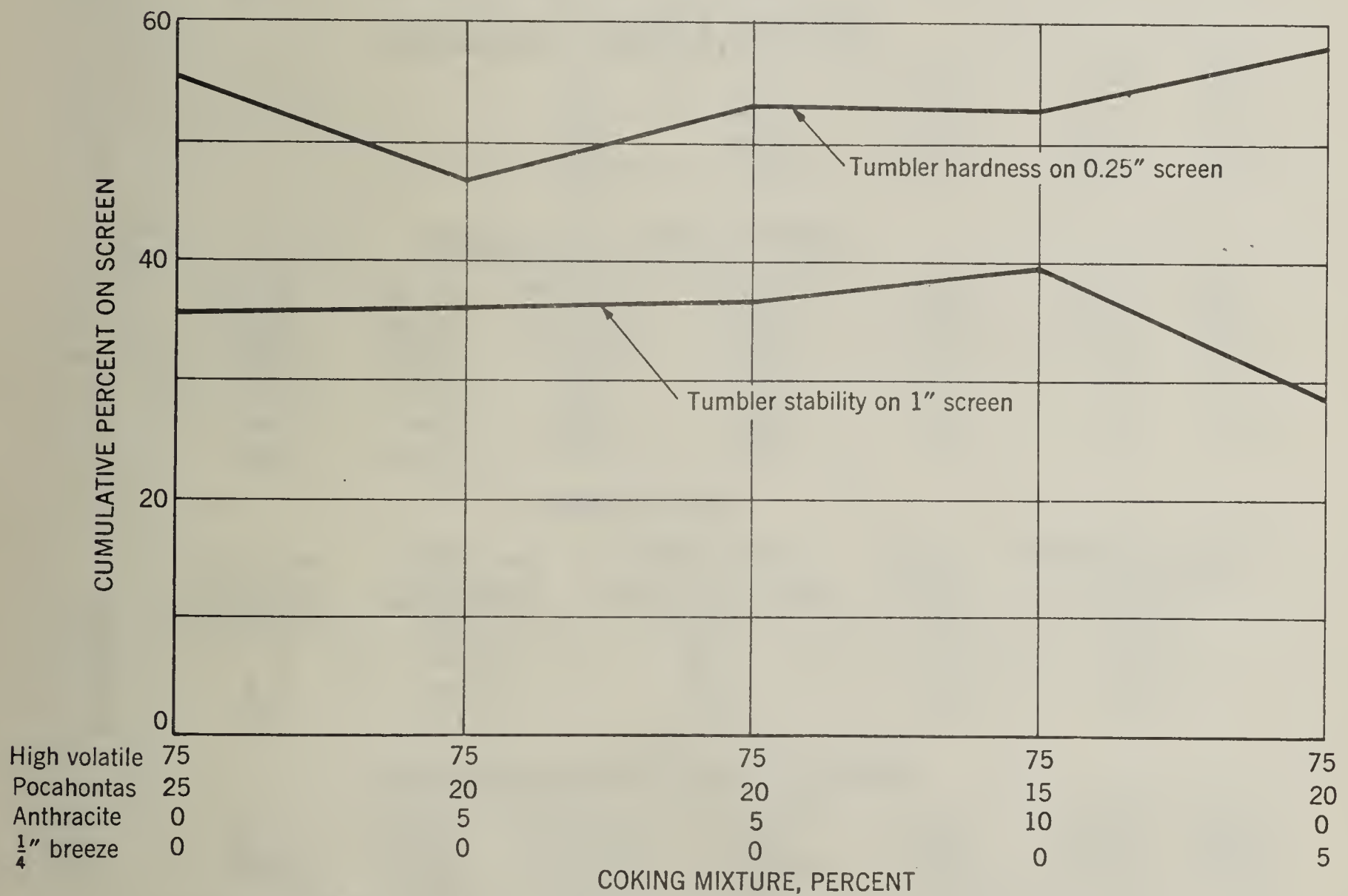


Figure 7.—Tumbler tests, showing effect of addition of anthracite fines to coking mixtures, commercial plant F.



TABLE 4. - Effect of addition of anthracite fines upon properties of coke (plant E)

Coals used:

High volatile - Eagle seam, West Virginia

Low volatile - Pocahontas No. 3, West Virginia

Anthracite No. 5 - volatile matter, 6.3 percent

| Mixtures: | Percent | | | |
|---------------------|---------|----|----|----|
| | 1 | 2 | 3 | 4 |
| High volatile | 80 | 95 | 80 | 85 |
| Low volatile | 20 | | 15 | 10 |
| Anthracite | | 5 | 5 | 5 |

SCREEN TESTSRun-of-oven coke

| Mixture | Percent | | | | | | |
|---------|-------------|-------------|-------------|-----------------|-------------|---------------|---------------|
| | +4- inch | +3- inch | +2- inch | +1-1/2- inch | +1- inch | +1/2- inch | -1/2- inch |
| 1 | 10.0 | 25.4 | 43.6 | 10.1 | 5.4 | 2.4 | 3.1 |
| 2 | 24.0 | 16.9 | 26.4 | 13.9 | 7.8 | 4.7 | 6.3 |
| 3 | 11.7 | 27.5 | 37.1 | 10.5 | 6.0 | 2.9 | 4.3 |
| 4 | 16.6 | 25.6 | 37.4 | 8.6 | 4.8 | 2.8 | 4.2 |

Crushed coke (double crushing)

| | | | | | | |
|---|--|------|------|------|------|------|
| 1 | | 24.1 | 31.2 | 26.5 | 9.6 | 8.6 |
| 2 | | 14.1 | 25.8 | 29.1 | 16.7 | 14.3 |
| 3 | | 18.9 | 33.8 | 24.9 | 11.2 | 11.2 |
| 4 | | 17.7 | 31.8 | 26.3 | 12.4 | 11.8 |

Shatter test (run-of-oven)

| | On 3- inch | On 2- inch | Total on 2-inch | +1-1/2- inch | Plus 1-inch | +1/2- inch | -1/2- inch |
|---|---------------|---------------|--------------------|-----------------|----------------|---------------|---------------|
| 1 | 14.0 | 45.0 | 59.0 | 23.1 | 11.9 | 3.4 | 2.6 |
| 2 | 21.5 | 42.2 | 63.7 | 15.3 | 11.1 | 5.3 | 4.6 |
| 3 | 24.1 | 44.0 | 68.1 | 18.2 | 7.7 | 3.0 | 3.0 |
| 4 | 20.3 | 46.3 | 66.6 | 18.4 | 8.4 | 3.2 | 3.4 |

Tumbler test

| | Total on 2-inch | Total on 1-1/2-inch | Stability total on 1-inch | On 1/2- inch | Hardness, total on 1/4-inch |
|---|--------------------|------------------------|------------------------------|-----------------|--------------------------------|
| 1 | 2.0 | 24.6 | 45.5 | 60.6 | 64.1 |
| 2 | 0 | 14.1 | 30.1 | 52.2 | 56.2 |
| 3 | 1.2 | 17.6 | 36.3 | 53.2 | 57.6 |
| 4 | 0.8 | 17.1 | 35.8 | 51.3 | 55.7 |

Repeated shatter tests (12 drops)

| | On 3- inch | On 2- inch | Total on 2-inch | On 1-1/2- inch | On 1- inch | On 1/2- inch | -1/2- inch |
|---|---------------|---------------|--------------------|-------------------|---------------|-----------------|---------------|
| 1 | 3.5 | 36.4 | 39.9 | 25.4 | 21.5 | 7.6 | 5.6 |
| 2 | 9.7 | 30.0 | 39.7 | 23.3 | 15.4 | 10.7 | 10.9 |
| 3 | 16.4 | 34.8 | 51.2 | 22.2 | 13.0 | 5.6 | 8.0 |
| 4 | 16.2 | 37.8 | 54.0 | 21.6 | 11.8 | 5.8 | 6.8 |

TABLE 5. - Effect of addition of anthracite fines upon
properties of coke (plant F)

| Coal mix | <u>1</u> percent | <u>2</u> percent | <u>3</u> percent | <u>4</u> percent | <u>5</u> percent |
|---|---------------------|---------------------|-----------------------|---------------------|---------------------|
| No. 2 Gas | 75 | 75 | 75 | 75 | 75 |
| Pocahontas | 25 | 20 | 20 | 15 | 20 |
| Anthracite | 0 | 5 | 5 | 10 | 0 |
| | | | 1/4-inch breeze | | 5 |
| Number of ovens ... | 15 | 11 | 15 | 1 | 16 |
| <u>Screen test, cumulative, percent</u> | | | | | |
| On 4-inch | 3.1 | 0.0 | 1.2 | 5.2 | 1.6 |
| On 3-inch | 22.2 | 28.8 | 20.7 | 36.7 | 22.8 |
| On 2-inch | 78.7 | 83.0 | 80.7 | 85.8 | 78.0 |
| On 1-1/2 inch | 96.6 | 96.5 | 97.2 | 97.0 | 95.3 |
| On 1-inch | 98.7 | 97.7 | 98.4 | 98.3 | 97.5 |
| On 1/2-inch | 99.4 | 98.7 | 99.1 | 98.9 | 98.7 |
| Through 1/2-inch .. | .6 | 1.3 | .9 | 1.1 | 1.3 |
| Over 2-inch | 78.7 | 83.0 | 80.7 | 85.8 | 78.0 |
| Under 2-inch | 21.3 | 17.0 | 19.3 | 14.2 | 22.0 |
| <u>Tumbler test (A.S.T.M.), percent</u> | | | | | |
| Stability factor .. | 35.5 | 36.0 | 36.6 | 39.8 | 28.9 |
| On 2-inch | 2.3 | 4.4 | 4.6 | 5.7 | 2.3 |
| On 1-inch | 33.2 | 31.6 | 32.0 | 34.1 | 26.6 |
| On 1/4-inch | 19.7 | 10.9 | 16.6 | 13.2 | 29.5 |
| Through 1/4-inch .. | 44.8 | 53.1 | 46.8 | 47.0 | 41.6 |
| <u>Porosity, percent</u> | | | | | |
| | 55.1 | 51.9 | 52.9 | 51.6 | 52.0 |

Plant H

The operators of this plant have used anthracite in their foundry mix for several years. They report that it increases the size and the shatter-test values of the coke.

Plant I

Plant-scale tests of foundry-coke mixtures containing anthracite fines indicated that the product would not meet the requirements of foundries supplied by this plant. Further tests with anthracite fines in mixtures used for coke for industrial purposes were made more recently the results of which have not been received to date.

Plant J

The standard mixture used at this plant was 70 percent high volatile, 30 percent low volatile. Several tests were made with various percentages of high volatile, low volatile, and anthracite fines. The blast-furnace coke is scalped over a 3-1/4-inch rotary grizzly and the over-size crushed to minus 4 inches. The tests indicated that the yield of blast-furnace coke (after crushing) from the mixtures containing 5 percent anthracite was 4 to 5 percent less than that from the standard mixture. The yield of blast-furnace coke from a mixture of 75 percent high volatile and 25 percent low volatile coal was about 1.4 percent less than that from the standard mixture. As the yield of blast-furnace coke is important at this plant, they preferred to go to a 75 high-volatile, 25 low-volatile mixture.

Plant K

At this plant complete replacement of 10 percent low-volatile coal with about 3.5 percent anthracite fines gave a reduction of furnace-coke yield and an increase in nut and breeze sizes. No change could be detected in the coke by shatter test. No tumbler tests were run. Results on blast-furnace practice were comparable to those from coke made from straight high-volatile coal and were generally unsatisfactory. Further experience with a mixture of 3 percent anthracite fines and 6 to 7 percent low volatile indicated that a satisfactory coke can be produced from such a mixture. The length of time that coke from these mixtures was used on the blast furnace was not given.

Plant L

The operators of this plant were among the first to employ anthracite fines in the coal mixture used for the manufacture of foundry coke. After several tests with various materials, they found that with 4 or 5 percent Pennsylvania anthracite in their foundry mixture their yield of foundry coke increased from 32 percent (without anthracite) to 50 percent. At the same time the coking time was decreased from 21-1/2 hours to 19 hours. Full details of their work are given in a paper by I. M. Roberts.^{7/}

Plant M

The quality of the coals used at this plant is below average. The ash content is rather high. The physical tests of coke from their normal mixture give low values. Addition of anthracite caused further deterioration in the quality of the coke, and results on the blast furnace were very unsatisfactory.

Plant N

The operators of this plant use anthracite fines in their mixture for foundry coke. Details are not available.

^{7/} Roberts, I. M., worked cited in footnote 6.

Plant O

The operators of this plant normally use a mixture of 86 percent high-volatile coal and 14 percent low-volatile coal. The coking rate is very high (about 1.27 inches per hour). Three tests were run on blast furnaces using coke made from a mixture containing 86 percent high-volatile coal, 10 percent low-volatile coal, and 4 percent anthracite fines. The longest test lasted 2 days and was discontinued because of excessive burning of tuyères. They also noted larger quantities of small coke at the tuyères. The tumbler and shatter test values were lower than those of the normal coke.

More recent oven-scale tests at this plant, in which 2 and 4 percent of the high-volatile coal was replaced with 2 and 4 percent of anthracite fines and one test in which the mixture containing 4 percent anthracite was treated with 0.75 gallon wash oil per ton of coal, produced cokes having higher average shatter-test values, approximately the same average tumbler hardness, and slightly average tumbler stability values, compared with cokes produced from the regular mixture. The results are shown graphically in figure 8, which gives the results of tests made at the plant, results of tests made by the Bureau of Mines on samples shipped to Pittsburgh, and the average results.

Plant P

Blast-furnace tests of mixtures containing anthracite fines some years ago were unfavorable. For 9 months the operators used 1.5 to 5 percent anthracite culm. During this period the minimum coking time was 30 hours, so the size of the coke was large, even under normal conditions. The addition of the anthracite made a larger and blockier coke, and as they scalp and crush the oversize, the production of breeze increased considerably. Under the conditions prevailing at the time the use of anthracite proved uneconomical. Recently tests have been started again, but the results to date do not check and are inconclusive. The tests are being continued.

Plant Q

The normal product at this plant is blast-furnace coke for use in the company's adjacent blast furnaces. The operators made a 1-month test using an average mixture of 57.9 percent high-volatile coal, 38.0 percent low-volatile coal, and 4.1 percent anthracite fines. The coking rate is rapid (1.22 inches per hour on a 19-inch oven), and the coke is pushed slightly "green", with green ends. The anthracite coke was larger and gave a higher shatter value than the normal coke (about 60 percent high-volatile coal, 40 percent low-volatile coal), but the other physical tests (6-foot drum) were lower. The breeze production was higher. The daily production of pig iron decreased about 6 percent and the coke used increased about 100 pounds per ton of iron. Details of this test are given in table 6.

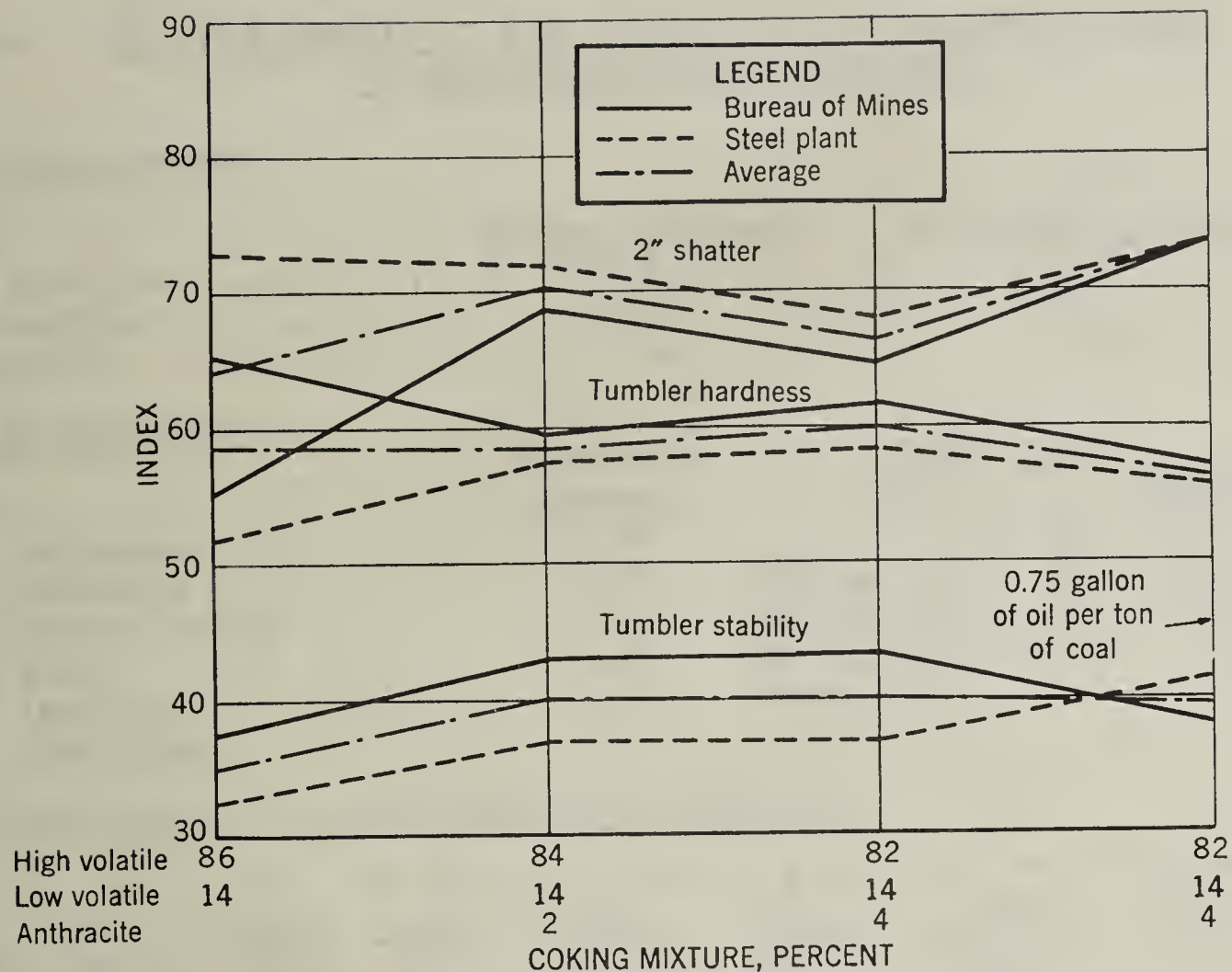


Figure 8.—Shatter and, tumbler tests, showing effect of addition of anthracite fines to coking mixtures, commercial plant 0.

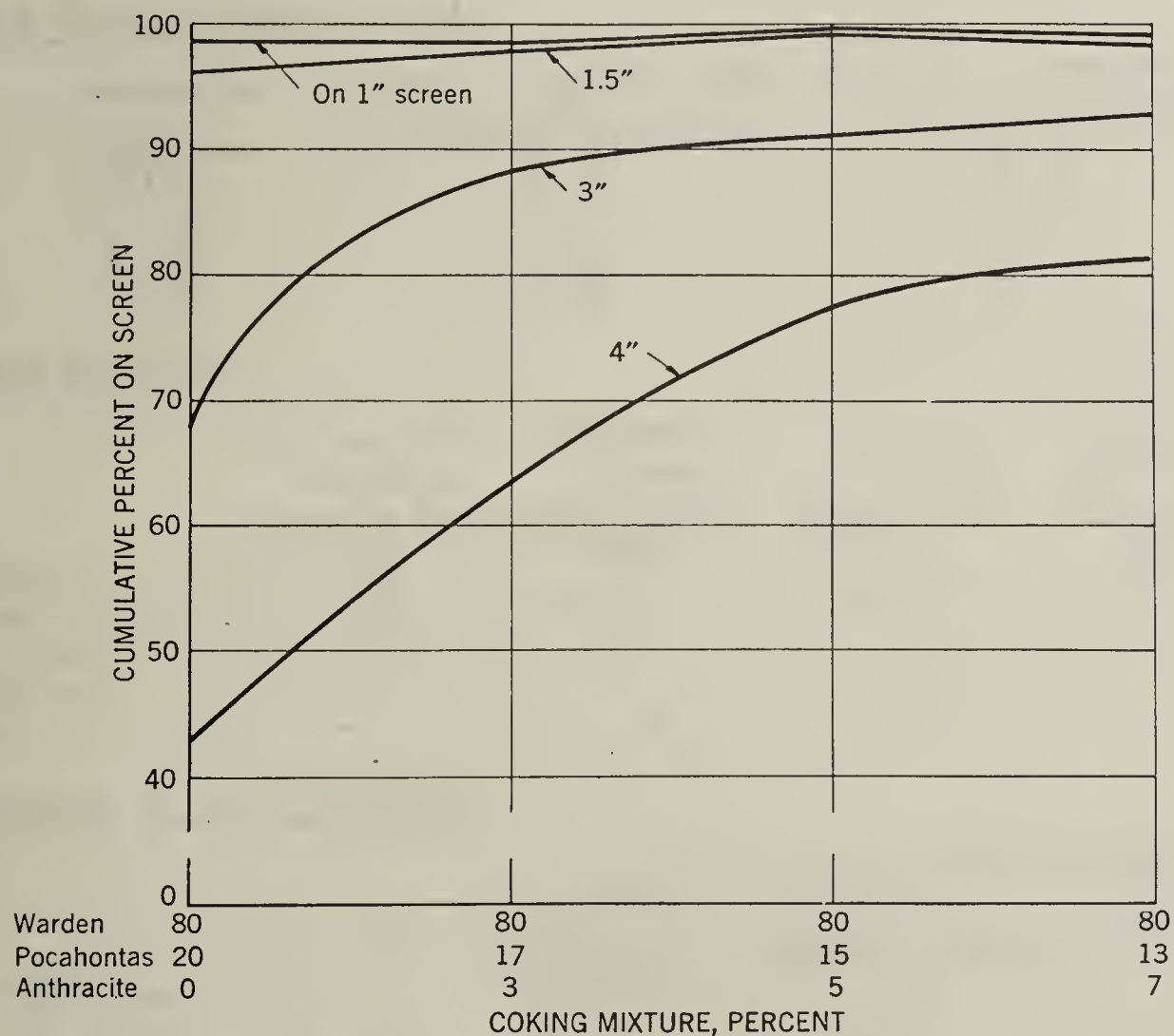


Figure 9.—Cumulative screen analysis, showing effect of addition of anthracite fines to coking mixtures, BM-AGA tests by Bureau of Mines.



Fig. 1. The effect of the variation of the temperature on the rate of reaction of the substance with oxygen.



Fig. 2. The effect of the variation of the temperature on the rate of reaction of the substance with oxygen.

TABLE 6. - Data and results of test on addition of anthracite fines to the coking mixture (plant Q)Average coking mixture:

| | <u>Normal, percent</u> | <u>With anthracite, percent</u> |
|---------------------|------------------------|---------------------------------|
| High volatile | 60.0 | 57.9 |
| Low volatile | 40.0 | 38.0 |
| Anthracite | | 4.1 |

Analysis of anthracite:

| | <u>Proximate, percent</u> | <u>Sieve test</u> | |
|----------------|---------------------------|-------------------|----------------|
| | | <u>Size</u> | <u>Percent</u> |
| Moisture | 10.30 | On 10 | 22.77 |
| (Volatile | 6.07 | Through 10 on 20 | 44.57 |
| (Fixed carbon | 80.39 | Through 20 on 40 | 28.29 |
| Dry basis (Ash | 13.54 | Through 40 on 100 | 3.87 |
| (Sulfur | .50 | Through 100 | .50 |
| (Phosphorus | .017 | | |

Average screen tests on blast-furnace coke, percent:

| | On 4-inch | 4- x 3- inch | 3- x 1- inch | 2- x 1- inch | 1- x 1-1/2- inch | Through 1/2-inch |
|--------------------|--------------|-----------------|-----------------|-----------------|---------------------|---------------------|
| Anthracite coke... | 12.59 | 17.60 | 39.05 | 26.70 | 3.31 | 0.75 |
| Normal coke | 5.43 | 10.42 | 39.01 | 40.46 | 3.93 | .75 |

Tumbler tests of coke (large drum):

| | <u>Anthracite coke</u> | <u>Average of regular coke 13 days before test</u> | <u>Average of regular coke 14 days after test</u> |
|-------------|------------------------|--|---|
| Value index | 87.59 | 97.26 | 96.14 |
| Strength | 79.29 | 82.20 | 81.30 |
| Hardness | 61.87 | 70.06 | 71.21 |
| Brittleness | 43.76 | 43.64 | 46.51 |

Blast-furnace practice:

| | <u>Average of 13 days before test</u> | <u>Average of 14 days after test</u> | <u>Average during test</u> | <u>Average for preceding full month</u> |
|--|---------------------------------------|--------------------------------------|----------------------------|---|
| Daily tonnage | 619 | 647 | 587 | 663 |
| Coke per ton iron..lb. | 1,651 | 1,493 | 1,593 | 1,491 |
| Coke breeze per ton of iron at the furnacesdo. | - | 56 | 80 | - |

Average analysis of coke, percent:

| | <u>Anthracite coke</u> | <u>Regular coke</u> | |
|-------------------------|------------------------|----------------------------|---------------------------|
| | | <u>13 days before test</u> | <u>14 days after test</u> |
| Moisture | 8.39 | 3.75 | 8.93 |
| (Volatile | 1.20 | 1.00 | 0.91 |
| Dry basis (Fixed carbon | 88.14 | 88.05 | 89.48 |
| (Ash | 10.67 | 10.94 | 9.60 |

Plant R

A few ovens of coke have been made from a mixture containing 80 percent high-volatile coal, 15 percent low-volatile coal, and 5 percent anthracite fines. The shatter-test value increased from 72 to 78 percent. Other results had not been assembled. The results were not satisfactory on account of the high ash content of the anthracite (26 percent).

Plant S

Tests were made at this plant upon a mixture of 80 percent high-volatile coal, 15 percent low-volatile coal, and 5 percent anthracite fines. The normal mixture is 80 percent high-volatile coal, 20 percent low-volatile coal. Only a few ovens of coke were made. The results of the tests were as follows:

| | <u>Anthracite mix</u> | <u>Normal mix</u> |
|------------------------|-----------------------|-------------------|
| Porosity | 51.14 | 54.09 |
| Shatter (on 2-inch) .. | 68.20 | 65.10 |
| Tumbler: On 1-inch .. | 40.00 | 43.60 |
| On 1/4-inch. | 58.20 | 63.20 |

Plans are being made to run a larger-scale test to determine the effects on blast-furnace operation.

Plant T

Normally this plant produces domestic coke and gas. During the war it has been making blast-furnace coke, which is used by a neighboring blast-furnace plant. Last spring it made oven-scale tests using anthracite fines. In these tests 6 percent low-volatile coal was replaced with 6 percent anthracite. The regular mix was 44 percent high-volatile coal, 44 percent medium-volatile coal, and 12 percent low-volatile coal. The shatter and tumbler tests compared favorably with those on the normal mixture. This company plans to make more extensive tests but cannot use anthracite in its blast-furnace mixture without the approval of the blast-furnace plant.

Plant U

This plant has replaced 4 percent Pocahontas with 4 percent anthracite in its foundry mix. It reports that the anthracite mix makes a more blocky coke and that 4 hours has been cut off the coking time.

TESTS BY THE BUREAU OF MINES

Some preliminary tests have been run in the BM-AGA apparatus at the Bureau of Mines Pittsburgh station on coking mixtures of Warden (Pittsburgh-bed) coal, Pocahontas coal, and anthracite (Buckwheat No. 5). Proximate and screen analyses of the coals used are given in table 7. Results of these tests are given in table 8 and shown graphically in figures 9, 10, and 11.

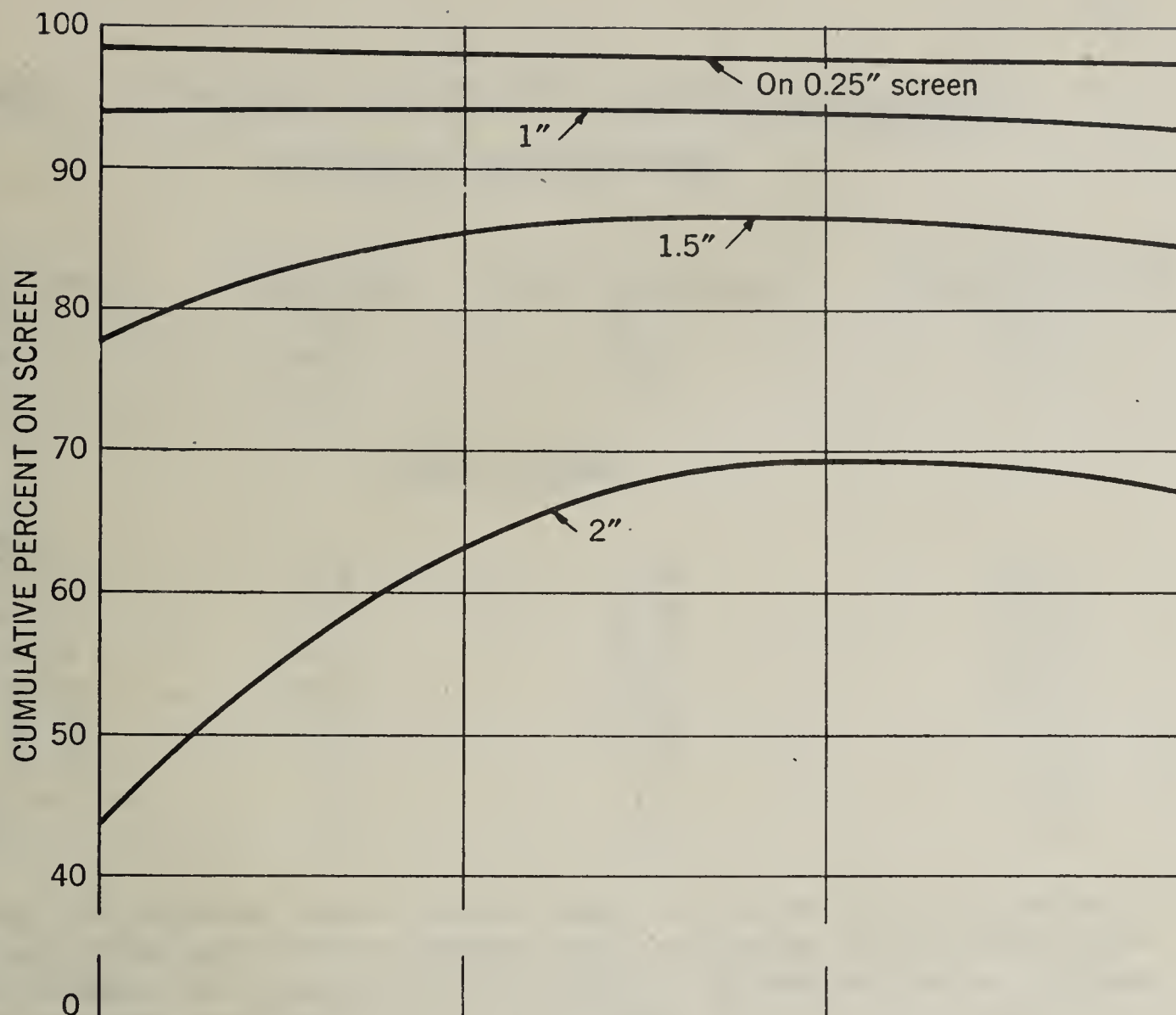


Figure 10.—Shatter tests, showing effect of addition of anthracite fines to coking mixtures, BM-AGA tests by Bureau of Mines.

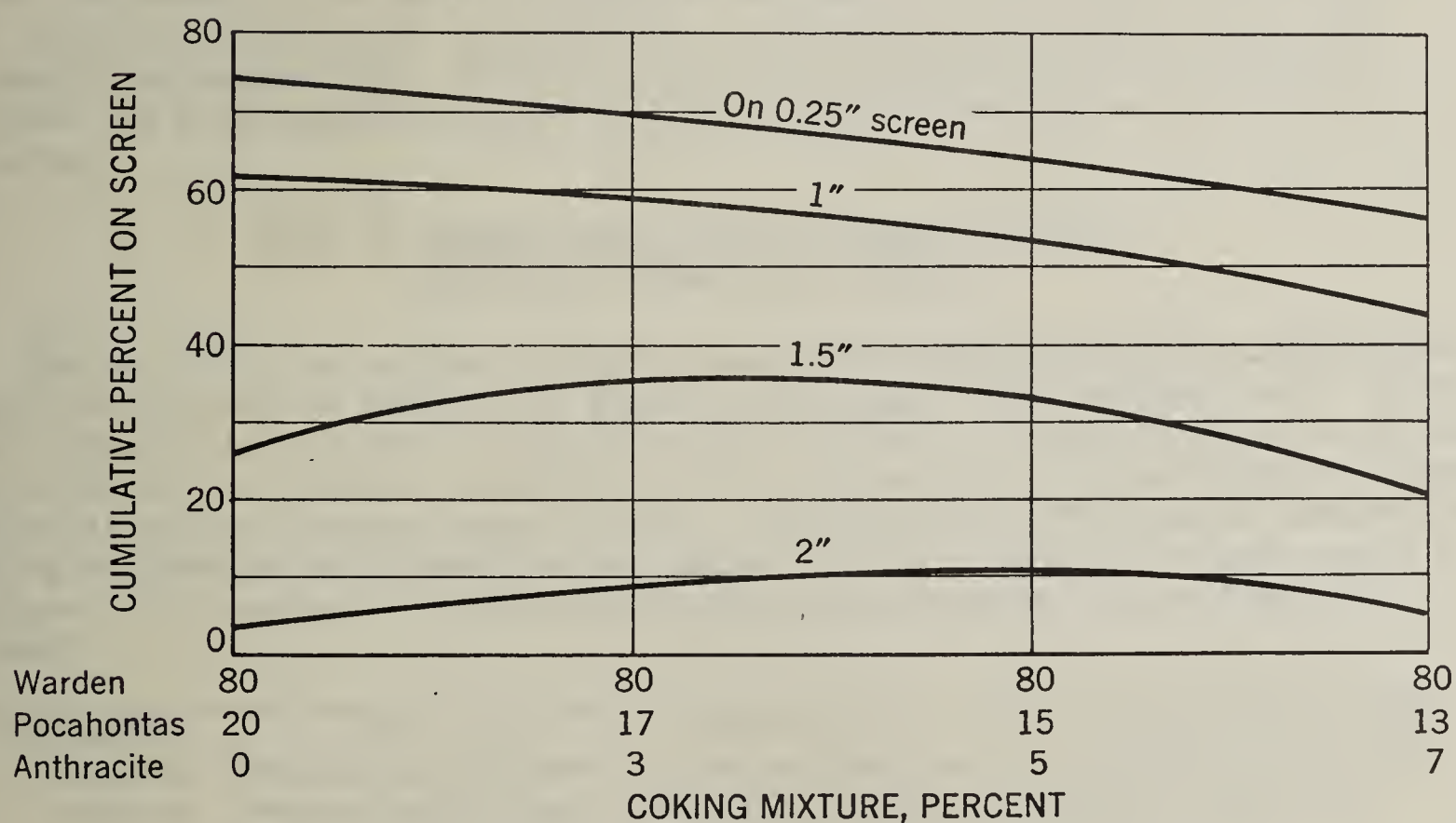


Figure 11.—Tumbler tests, showing effect of addition of anthracite fines to coking mixtures, BM-AGA tests by Bureau of Mines.



The variation of the ratio of the maximum to the minimum value of the function $f(x)$ as a function of the parameter x .



The variation of the ratio of the maximum to the minimum value of the function $f(x)$ as a function of the parameter x .

TABLE 7. - Analyses of coals used in BM-AGA tests, percent

PROXIMATE (MOISTURE-FREE)

| Constituents | Anthracite | Pocahontas No. 3 | Warden (Pittsburgh bed) |
|--------------------|------------|------------------|----------------------------|
| Volatile | 5.6 | 17.7 | 36.6 |
| Fixed carbon | 79.5 | 76.1 | 57.3 |
| Ash | 14.9 | 6.2 | 6.1 |

SIZE ANALYSES

| Mesh | | | |
|-------------------------|------|------|------|
| Tyler on 4 | 0.0 | 2.6 | 29.8 |
| Through 4 on 8 | .6 | 19.8 | 37.3 |
| Through 8 on 14 | 16.8 | 27.6 | 16.2 |
| Through 14 on 35 | 70.9 | 28.6 | 10.4 |
| Through 35 on 80 | 11.0 | 11.3 | 3.6 |
| Through 80 on 150 | .5 | 4.0 | 1.0 |
| Through 150 on 200 ... | .1 | 1.7 | .8 |
| Through 200 | .1 | 4.4 | .9 |

Although the physical tests on coke made in the cylindrical retort of the BM-AGA apparatus may differ somewhat from coke made in byproduct-coke ovens, nevertheless the tendency of the addition of anthracite to increase the size of the coke and shatter test is clearly indicated in both cases.

The tumbler tests on the BM-AGA coke show a practically linear decrease in the hardness factor and a progressive decrease in the 1-inch stability with increased percentage of anthracite. These tests were made with only one sample of anthracite. Further tests using anthracites of different analyses and high-volatile coals from different fields and beds would be valuable.

WORK OF PENNSYLVANIA STATE COLLEGE, MINERAL
INDUSTRIES EXPERIMENT STATION

During 1944 this college issued a bulletin on the Technical and Economic Aspects of the Use of Anthracite Fines in Byproduct Coke Production.^{8/} This paper reviews the subject in general and includes thorough discussions of both its technical and economic aspects. It is interesting to note that the author, apparently having foundry coke in mind, concludes that "The use of several percent of anthracite will permit a reduction in coking time and consequently an increase in throughput conservatively estimated to amount to at least 10 percent".

^{8/} Clendenin, J. D., Barclay, K. M., and Wright, C. C., The Technical and Economic Aspects of the Use of Anthracite Fines in Byproduct Coke Production: Pennsylvania State College, School of Mineral Industries, Circ. 16, State College, Pa., 1944, 104 pp.

TABLE 8. - Physical tests of coke from blends of Warden, Pocahontas No. 3,
and anthracite No. 5 Buckwheat

SCREEN ANALYSIS

| Description | Percent | Percent | | | | | |
|---------------------------------|---------|---------------|---------------|---------------|----------------|---------------|-------------------|
| | | On 4- inch | On 3- inch | On 2- inch | 1-1/2- inch | On 1- inch | Through 1-inch |
| Warden | 80 | 42.8 | 68.2 | 88.0 | 96.4 | 98.8 | 1.2 |
| Pocahontas No. 3 | 20 | | | | | | |
| Anthracite No. 5 Buckwheat | 0 | | | | | | |
| Warden | 80 | 65.9 | 88.4 | 96.2 | 97.9 | 98.4 | 1.6 |
| Pocahontas No. 3 | 17 | | | | | | |
| Anthracite No. 5 Buckwheat | 3 | | | | | | |
| Warden | 80 | 77.4 | 90.8 | 97.4 | 99.1 | 99.7 | 0.3 |
| Pocahontas No. 3 | 15 | | | | | | |
| Anthracite No. 5 Buckwheat | 5 | | | | | | |
| Warden | 80 | 81.4 | 92.6 | 97.3 | 98.5 | 99.2 | 0.8 |
| Pocahontas No. 3 | 13 | | | | | | |
| Anthracite No. 5 Buckwheat | 7 | | | | | | |

SHATTER AND TUMBLER TESTS

| Description | Percent | Shatter test, percent upon | | | | Tumbler test, percent upon | | | |
|----------------------------|---------|-------------------------------|----------------|------------|--------------|-------------------------------|----------------|-----------|--------------|
| | | 2- inch | 1-1/2- inch | 1- inch | 1/4- inch | 2 inch | 1-1/2- inch | 1 inch | 1/4- inch |
| Warden | 80 | 43.8 | 77.8 | 93.9 | 98.5 | 3.8 | 26.4 | 61.7 | 74.9 |
| Pocahontas No. 3 | 20 | | | | | | | | |
| Anthracite No. 5 Buckwheat | 0 | | | | | | | | |
| Warden | 80 | 65.5 | 85.6 | 93.9 | 98.1 | 8.2 | 35.5 | 57.3 | 68.3 |
| Pocahontas No. 3 | 17 | | | | | | | | |
| Anthracite No. 5 Buckwheat | 3 | | | | | | | | |
| Warden | 80 | 69.3 | 86.6 | 94.0 | 97.6 | 10.8 | 33.7 | 53.1 | 63.4 |
| Pocahontas No. 3 | 15 | | | | | | | | |
| Anthracite No. 5 Buckwheat | 5 | | | | | | | | |
| Warden | 80 | 67.2 | 84.6 | 93.2 | 97.5 | 4.1 | 25.4 | 43.9 | 56.0 |
| Pocahontas No. 3 | 13 | | | | | | | | |
| Anthracite No. 5 Buckwheat | 7 | | | | | | | | |

More recently the same authors presented a paper at Charleston, W. Va., entitled "Factors Influencing Suitability of Different Anthracites for Blending."^{9/} This paper gives the results of their laboratory research work done on 27 samples of anthracite fines from various collieries in the four major anthracite fields. The work included studies of the inherent strength of the raw and thermal treated coals, decrepitation caused by thermal treatment, and laboratory-scale coking tests. The coking tests indicate that anthracites with low volatile matter and high specific gravity tend to make a larger and blockier coke than that made from anthracites with high volatile matter and low specific gravity. Also that, in most cases, the anthracites with high volatile content and low specific gravity made a coke which, though smaller, was more resistant to abrasion. Their tests also indicate that the size of the anthracite is an important factor. Apparently the 40- to 60-mesh size made the strongest coke. Confirmation of their conclusions by tests on an oven-scale basis under actual operating conditions would be a very valuable contribution.

GENERAL DISCUSSION OF PLANT RESULTS

As a result of their actual operating experience, plant operators using anthracite in the production of foundry coke have determined that anthracite with low volatile content and high specific gravity gives the best results. However, actual operating data is too meager to check the effects of the higher-volatile anthracites.

The proximate analyses and sieve analyses of several of the anthracite fines used in operation and in testing at various plants are given in table 9. These analyses are as reported by the operators.

Some complaints have been registered by plant operators regarding the quality of the anthracite fines received. Anthracite fines with an ash content of not over 15 percent are available. The Solid Fuels Administration is prepared to advise as to sources of anthracite of the proper grade and analysis.

One of the difficulties with which coke-oven operators have to cope is the unloading of coal from railroad cars during freezing weather. As anthracite fines usually contain about 10 percent water, the coal in cars is liable to freeze into a compact mass. Unless a plant is equipped with thaw sheds or some adequate means of thawing cars, anthracite fines will prove very difficult to handle in severe weather. This trouble can be avoided by stocking enough anthracite to last through the severely cold weather.

^{9/} Clendenin, J. D., Barclay, K. M., and Wright, C. C., Use of Anthracite Fines in Byproduct Coke Production. Factors Influencing the Relative Suitability of Different Anthracites for Blending: Paper presented at joint meeting of Am. Soc. Mech. Eng. Fuels Division and Am. Inst. Min. and Met. Eng. Coal Division at Charleston, W. Va., October 30-31, 1944.

TABLE 9. - Analyses of anthracite fines as reported by oven operators, percent

PROXIMATE ANALYSIS

| Plant | H ₂ O | Volatile matter | Fixed carbon | Ash | Sulfur |
|-------|------------------|-----------------|--------------|-------|--------|
| A * | 0.0 | 4.0 | 82.1 | 13.9 | 0.66 |
| B * | 9.26 | 5.73 | 77.77 | 16.50 | .504 |
| D ° | 11.7 | 4.7 | 79.8 | 15.5 | .48 |
| E | 10.3 | 6.3 | 79.6 | 14.1 | .50 |
| G * | 13.5 | 5.38 | 77.56 | 17.06 | .55 |
| H ° | 11.8 | 8.0 | 77.9 | 14.1 | .53 |
| J | 12.0 | 9.05 | 77.73 | 13.22 | .63 |
| K * | 12.0 | 7.12 | 79.32 | 13.54 | .68 |
| L ° | 10.83 | 5.51 | 76.73 | 17.76 | .51 |
| O | 6.19 | 7.46 | 75.70 | 16.84 | .75 |
| Q | 10.89 | 6.07 | 80.54 | 13.39 | - |
| S | 11.40 | 8.60 | 79.85 | 11.55 | .62 |
| T | 11.25 | 8.15 | 80.65 | 11.20 | .86 |
| U ° | 11.25 | 6.06 | 80.96 | 12.98 | - |

SCREEN ANALYSIS

| Plant | On 10 | Through 10 on 20 | Through 20 on 40 | Through 40 on 100 | Through 100 |
|-------|-----------------------|------------------------|-------------------------|-------------------------|------------------------------|
| A | 4.6 | 48.6 | 36.3 | 9.0 | 1.5 |
| B | .4 | 47.7 | 45.4 | 5.2 | 1.3 |
| D | 2.0 | 51.0 | 33.0 | 12.0 | 2.0 |
| G | 8.75 | 67.50 | 22.50 | .30 | .95 |
| L | .2 | 23.4 | 62.4 | 13.5 | .5 |
| Q | 22.7 | 44.6 | 28.3 | 3.9 | .5 |
| S | 3.4 | 40.1 | 38.7 | 14.7 | 3.1 |
| E | On 10 M 13.6 | 10 x 20 M 60.2 | 20 x 48 24.6 | 48 x 100 1.2 | Through 100 0.4 |
| U | .2 | 34.4 | 61.4 | 3.0 | 1.0 |
| H | On 31/16-in. .6 | 3/16 x 3/32-in. 2.2 | 3/32 x 1/16-in. 13.7 | 1/16 x 3/64-in. 33.3 | Through 3/64-inch 50.2 |
| J | Plus 1/4-inch 0.84 | | 1/4 x 1/8-inch 1.60 | | Minus 1/8-inch 97.56 |
| K | - | | - | | 100.0 |

* Plants now using anthracite in regular production of blast-furnace coke.

° Plants now using anthracite in regular production of foundry coke.

Shorter coking time made possible by the use of anthracite fines in the coking mixture applies more especially to foundry coke. Ordinarily the coking time for foundry coke is much longer and the coking temperatures somewhat lower than for blast-furnace coke. The increase in the size of the coke caused by the addition of anthracite fines to the coal mixture enables the foundry coke maker to cut his coking time and increase his production. Of

course, he must increase his coking temperature to coke the charge completely during the shorter coking time. When the blast-furnace coke maker is running to capacity, his coking temperature is usually near the top safe temperature; therefore he cannot expect to be able to shorten his coking time when anthracite is used.

CONCLUSIONS AND RECOMMENDATIONS

1. Study of the data and information obtained from the plants visited indicates that the effects of the additions of anthracite fines to coking mixtures varies considerably with the nature of the bituminous coals used and the operating conditions at the plant. Thus it becomes apparent that the use of anthracite fines is an individual plant problem.
2. A few plants are successfully using 4 to 5 percent anthracite fines in their mixtures for the production of blast-furnace coke, and it is indicated that many other byproduct-coke plants can substitute 3 to 5 percent anthracite fines for the same percentage of Pocahontas coal without any serious effects on their blast-furnace operation.
3. Until further information is available, it is indicated that where a choice exists the lower-volatile anthracite should be used. However, it is a controversial matter, and oven-scale tests with some of the high-volatile anthracite fines by plants where such tests can be made would have considerable value.
4. The effect of addition of anthracite may vary with the rank, field, or seams of all of the coals used. If a plant has the facilities for making oven-scale tests, preliminary tests of various mixtures or blends will be of considerable value in determining the best combination. If not, probably the best procedure is to start with the lowest practical percentage of anthracite fines and gradually increase the same and at the same time change the percentages of high and low volatile as observation of the results may indicate.
5. As the shortage of Pocahontas coal is serious, it is important that the percentage of Pocahontas coal used be decreased wherever possible.
6. Anthracite fines should be stocked for winter use.

The first of these is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. It is a system that is not easily understood, and it is one that is not easily understood.

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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

MAGNETIC SURVEY OF THE FLORIDA PENINSULA

APR 15 '48



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ST.

BY

F. W. LEE, J. H. SWARTZ, AND S. J. HEMBERGER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MAGNETIC SURVEY OF THE FLORIDA PENINSULA^{1/}

By F. W. Lee,^{2/} J. H. Swartz,^{3/} and S. J. Hemberger^{4/}

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^{1/} The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3810."

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INTRODUCTION

This investigation was undertaken in 1939 for the purpose of securing the necessary information relating to the field techniques and accuracy that would be needed for magnetically surveying State-wide areas. The Florida peninsula was chosen for such a study for two reasons: First, because it is geologically ideal for such an investigation, since it comprises a series of unconsolidated, flat-lying Tertiary and Cretaceous sediments of low magnetic susceptibility covering a complex and much-folded crystalline basement comprised of rocks carrying strongly paramagnetic materials; second, because information concerning the structural trends of the crystalline basement would be of great interest and importance in the study of Appalachian orogeny and the relationship of the Florida peninsula to both the Appalachian and Antillean tectonic systems. The results of this magnetic survey have clearly demonstrated that the magnetic anomalies reflect variations in the crystalline basement. To the degree which the structures of the crystalline basement control the structures of the overlying sediments these results are useful for oil exploration.

MAGNETIC OBSERVATIONS

All magnetic measurements were made with a vertical Askania magnetic variometer having a temperature compensated needle. All observations were tied into two base stations located at Fort Myers and Gainesville, Fla. The absolute vertical magnetic intensities at these two base stations were determined by the United States Coast and Geodetic Survey within an accuracy of ± 10 gammas. The accuracy of the base station variometer used in the present survey was of the order of ± 3 gammas. The sensitivity throughout the survey of the magnetic variometer used on the traverses approximated 30 gammas per scale division and it is estimated that the probable error between stations along a traverse would be about ± 5 gammas. Measurements were started on traverse C near Fort Myers and tied into the Fort Myers base station established by the Coast and Geodetic Survey. Twelve traverses, comprising 1,500 station observations, were occupied between the Fort Myers and Gainesville base stations. When the cumulative total of these 1,500 interim observations was tied into the Gainesville base station it was found to differ by only 50 gammas from the value obtained by the Coast and Geodetic Survey for that base. The observations were adjusted for this difference.

All measurements were corrected for diurnal variations, using base-station observations. Wherever it was necessary to make latitude adjustments a calibration of the magnetometer was made by a special calibration coil, which was attached as an integral part of the magnetometer.

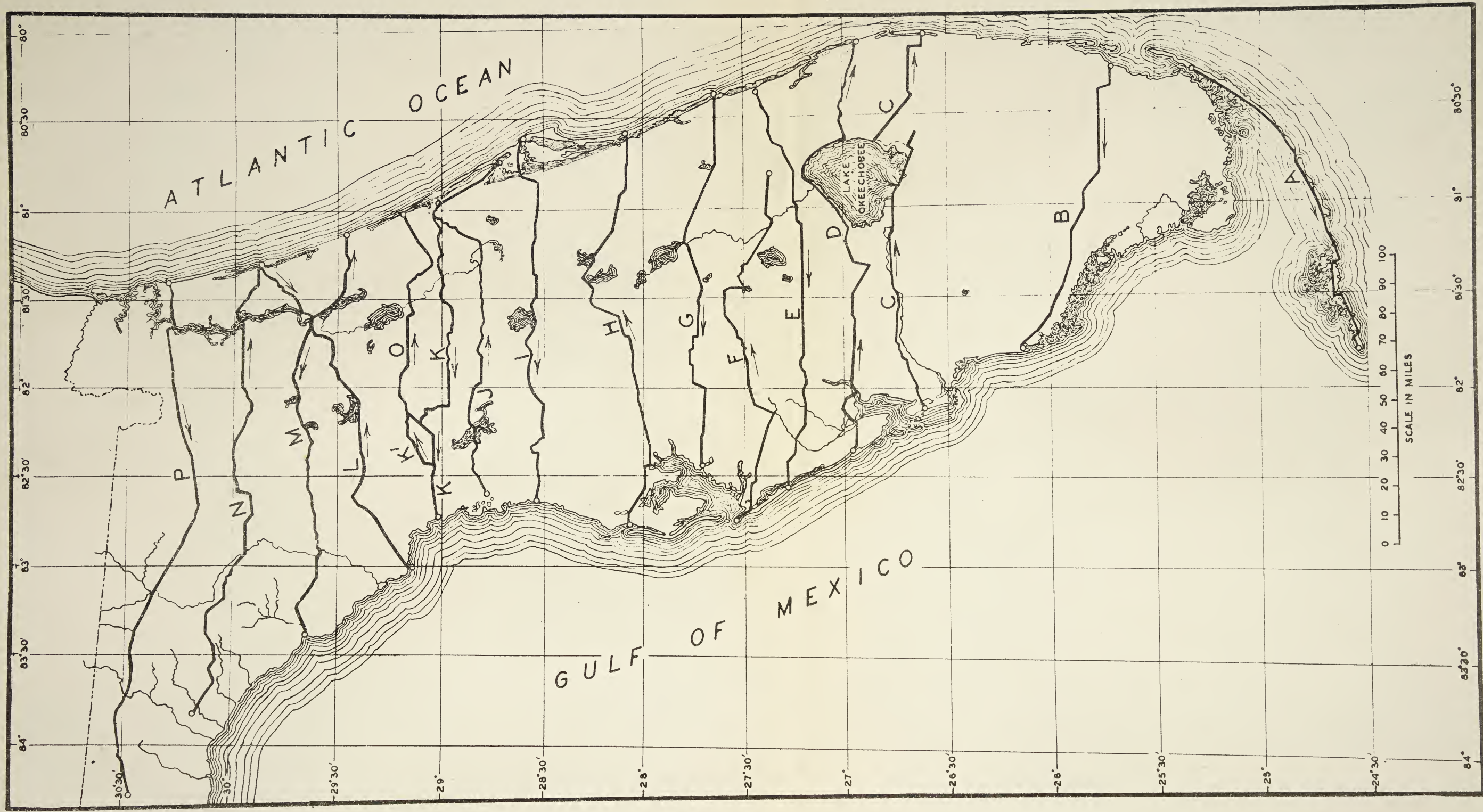


FIGURE 1 - MAP OF FLORIDA PENINSULA SHOWING LOCATION OF MAGNETOMETER TRAVERSES.

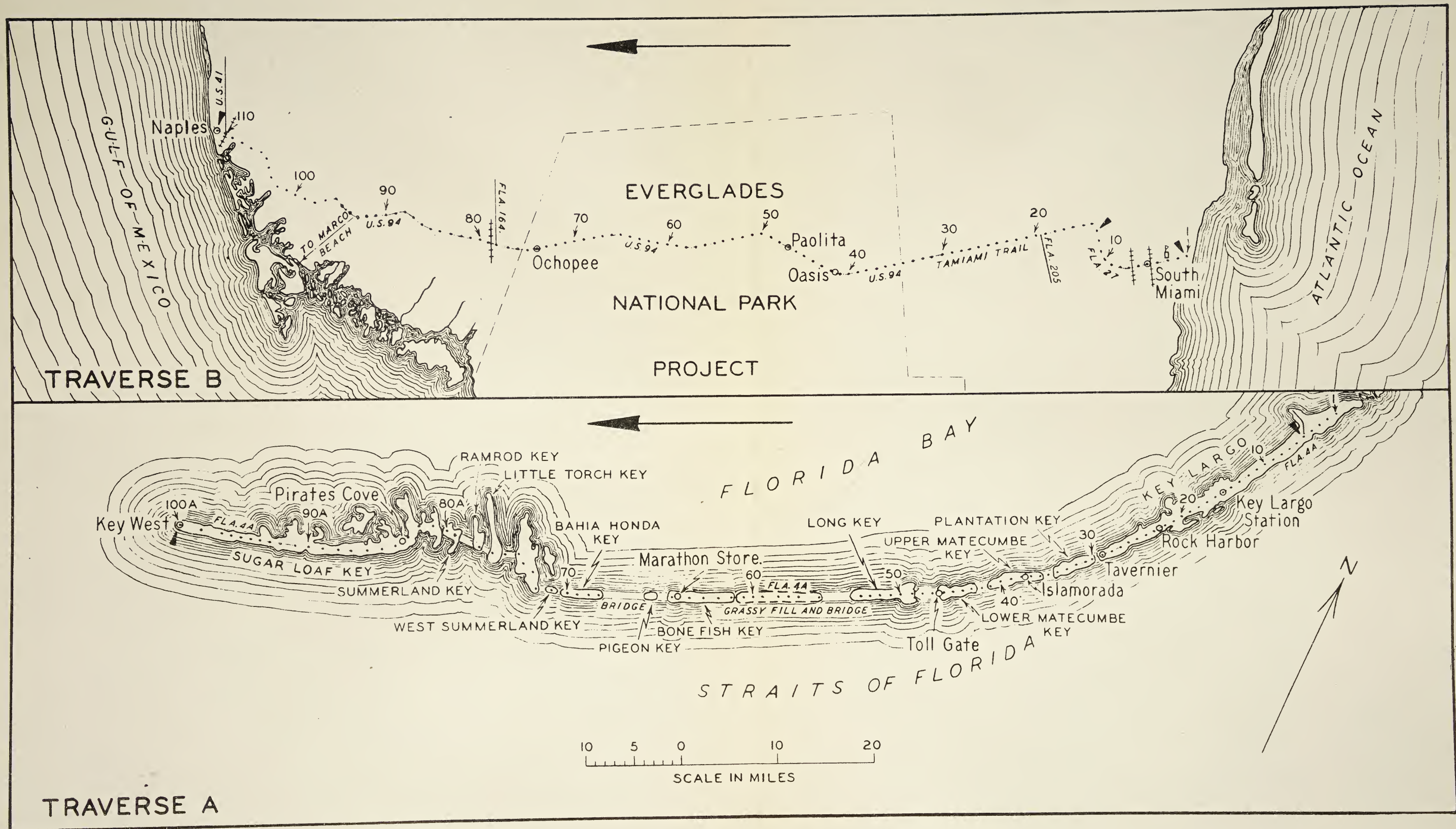


FIGURE 2.-TRAVERSE CHARTS OF A AND B.

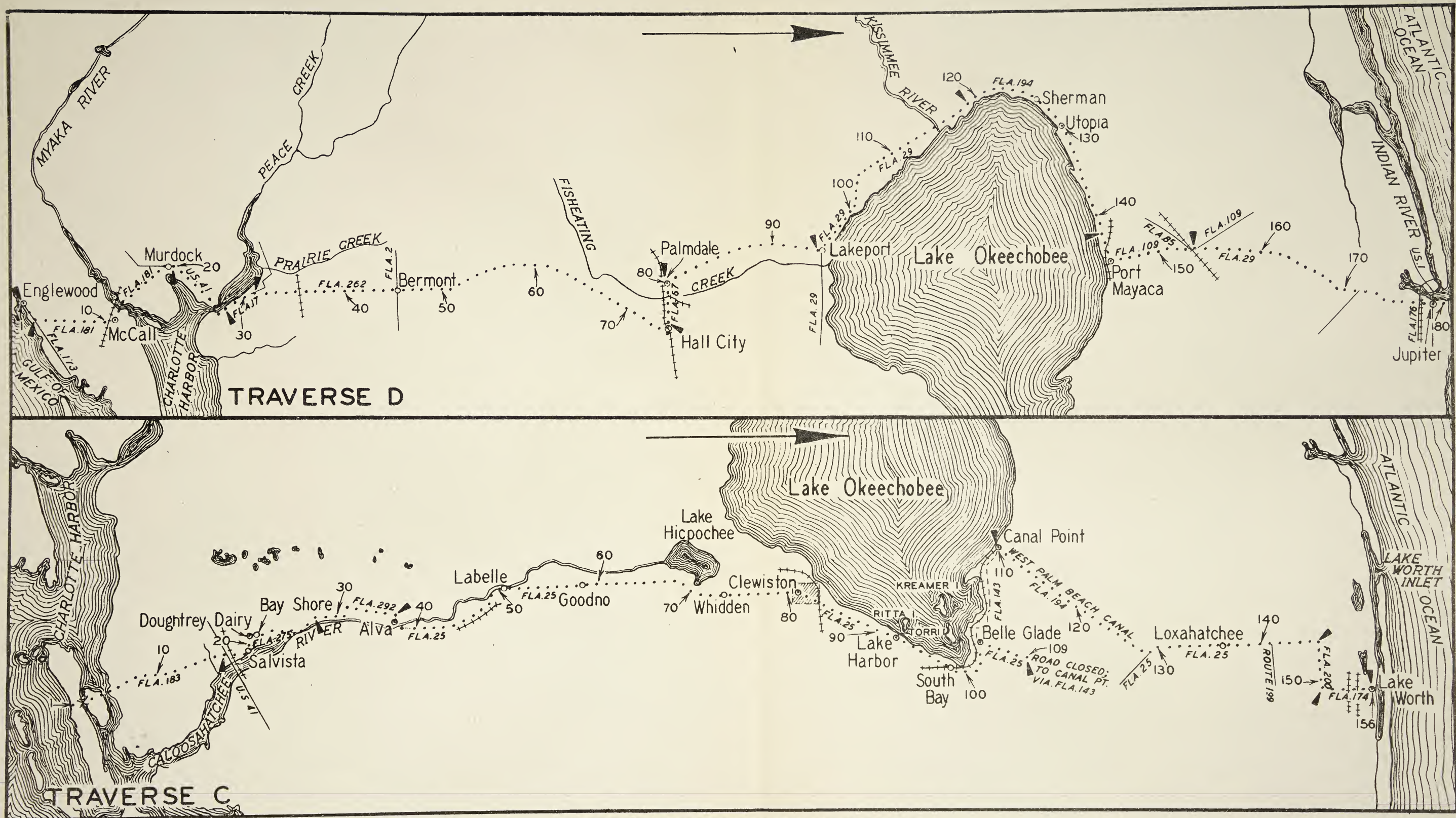
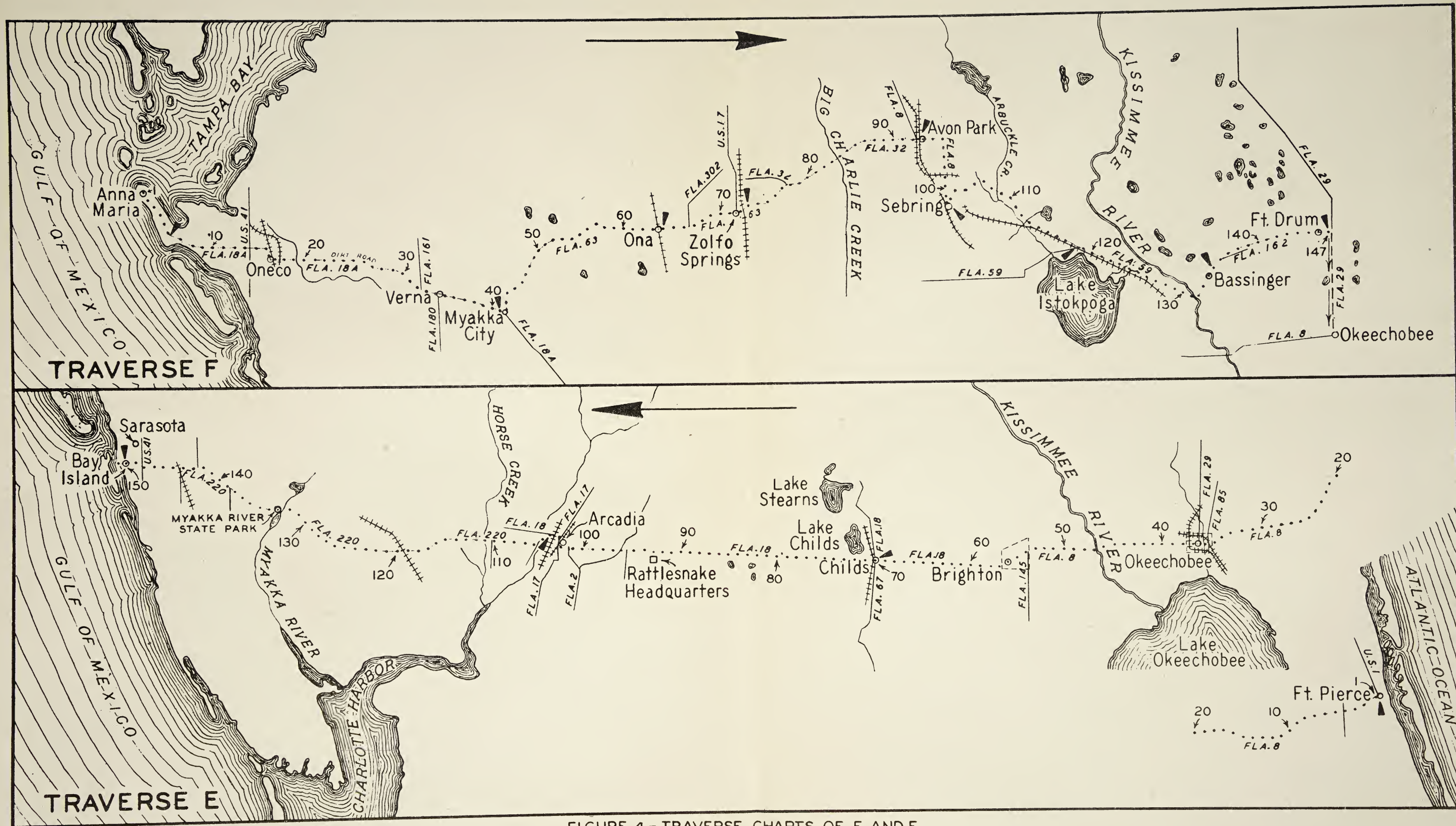


FIGURE 3.- TRAVERSE CHARTS OF C AND D.



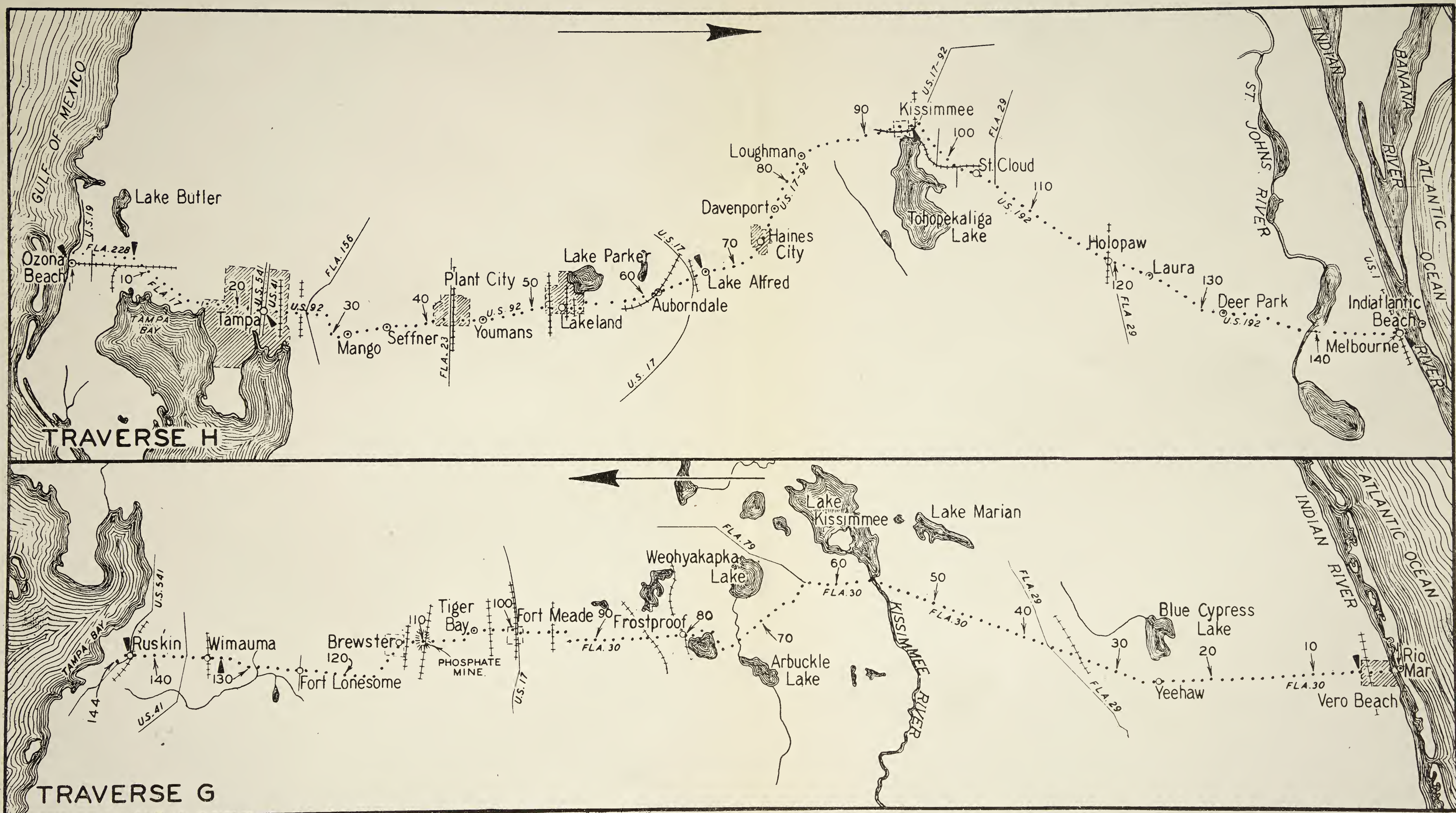


FIGURE 5.- TRAVERSE CHARTS OF G AND H.

Observations along traverses were made wherever possible at 1-mile intervals, using the automobile speedometer for measuring the interval. No observations were made on bridges or other causeways containing steel in the reinforced concrete. Also, all observation stations were offset some distance from the main highway, to preclude any possibility of error due to road materials or iron that might have been buried by road excavation work. Wherever observations were made on fills it was so indicated on the traverse data sheets.

In the preparation of the traverse data and maps, observed distances have been included as recorded on the data sheets. Additional culture taken from automobile and Bureau of Public Roads maps, agricultural maps, and other sources of information considered reliable has been added to the traverse maps to assist in identifying the location of the stations. Every tenth station on such traverses has been numbered for ease in identification. Railroad crossings and road intersections have been shown and probably constitute the most permanent markers for resurvey purposes at some later date.

The field observations were made between February 20 and April 14, 1939, except for traverse O, which had been run in December 1937. Traverse C was run first, followed by traverses A, B, D, E, F, G, H, I, J, K, L, M, N, P, and K' in order. The distances between the traverses varied from 20 to 40 miles. In all about 2,300 observations were made in an area of some 50,000 square miles. Figure 1 is an index map showing the locations and designations of the separate traverses.

MAGNETIC TRAVERSES

Traverses A and B are shown in figure 2. Traverse A begins at the northern portion of Key Largo and ends at Key West. The measurements on this traverse were taken on the keys, and no stations were measured on the concrete structures or cement road which comprise large stretches in this interval. Traverse B begins on the beach of South Miami and follows the Tamiami Trail to Naples. Wherever possible the measurements were made off the trail in the Everglades. Owing to fires which were raging at the time this work was underway it was impossible to run magnetic traverses along trails in the Everglades.

Traverses C and D are shown in figure 3. Both traverses were run from west to east. Traverse C was interrupted by road construction and was finished by way of Canal Point to Lake Worth. Traverse D started at Englewood and followed the northern shore to Lake Okeechobee to Jupiter.

Traverses E and F are shown in figure 4. Both traverses were regular except the areas around Fort Drum. Due to their location on Indian reservations the roads were more or less trails in this region. Owing to deep sands, gulleys, etc., in this area measurement locations were reached with great difficulty.

Traverses G and H are shown in figure 5. Both traverses were normal except for that part of traverse H through the Tampa area, where little was known concerning possible buried iron.

Traverses I and J are shown in figure 6. Both traverses were regular. It should be noticed, however, that traverse J, between stations 127 and 151, is measured parallel to the Atlantic Ocean coast line.

Traverses K, K', L, and O are shown in figure 7. All of these traverses were regular. Traverse K' was made around the York well, whose location is better seen in figure 1. It should be noticed that New Smyrna Beach is common to both the J and K traverses.

Traverses M, N, and P are shown in figure 8. Gainesville, the second base station, was on traverse M. The area around Jacksonville on traverse P contained possible uncertainties due to buried iron.

CHARTING OF MAGNETIC OBSERVATIONS

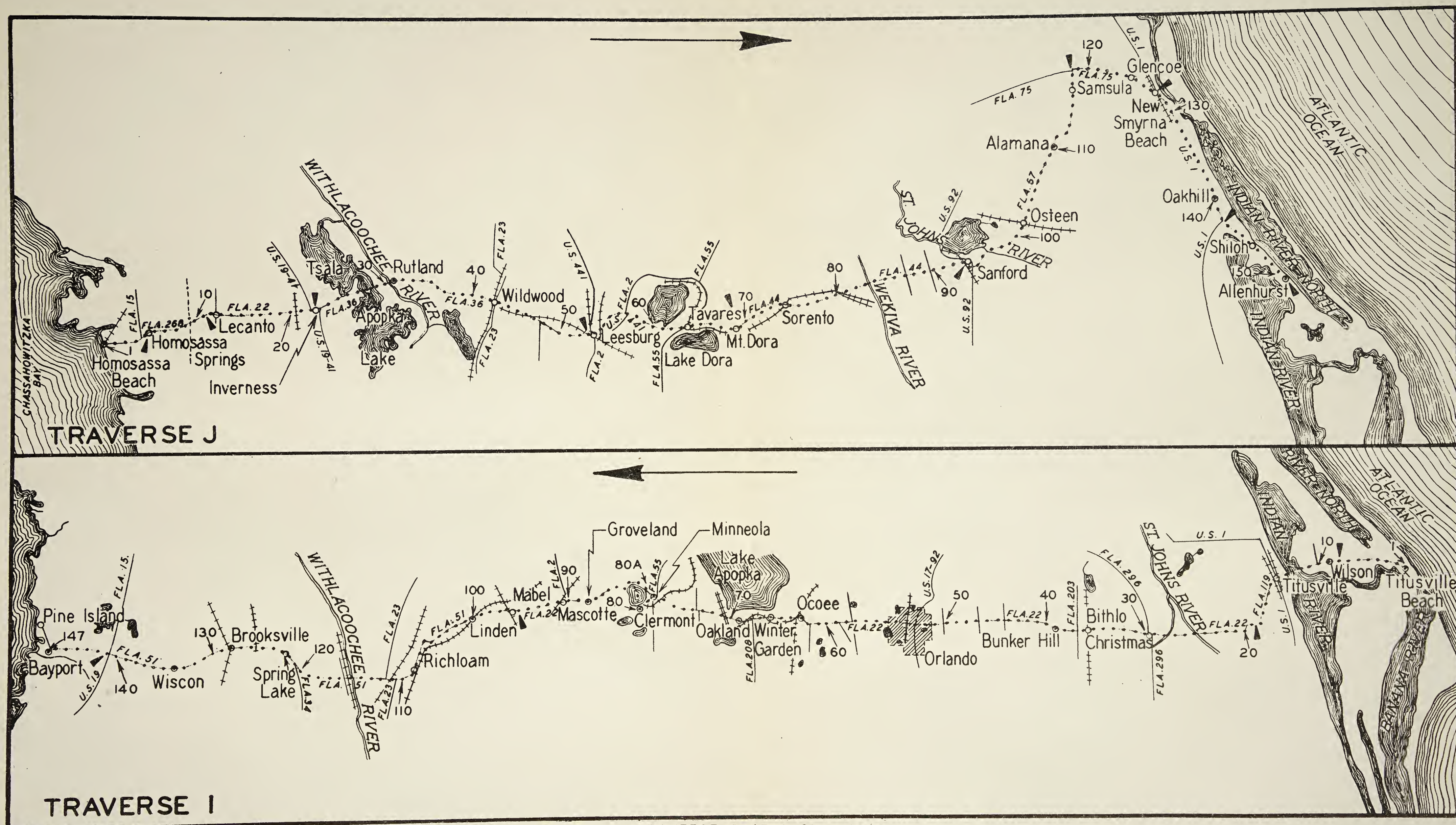
Although little difficulty is experienced in charting magnetic values on small-scale surveys comprising small areas or regions, the problem becomes more complicated for State-wide surveys. Both major and minor magnetic anomalies and the structural and tectonic features associated with them may be important in their relation to possible oil accumulations. Intimately tied into these magnetic anomalies are changes due to latitude and longitude, and it was a difficult matter clearly to separate the effects of all of these different factors. It was finally decided to represent the magnetic observations as a continuous surface passing through the actual measured values in the form of the magnetic relief map shown in figure 9. This map was prepared by (1) constructing a model of the magnetic measurements, (2) photographing the model, and (3) stippling the surface of the model in the photograph to bring out the magnetic relief.

The large features sought for in oil-exploration work are clearly defined on the relief map. It will also be noted that had the customary magnetic contour maps been drawn it would have been difficult to envisage so well the full meaning and value of the magnetic survey.

It is seen that the general effect of latitude is gradually to raise the magnetic relief surface as the northern portion of the peninsula is approached. If the averages of the magnetic values for each traverse are plotted against the average latitude value for the traverses, a straight line is obtained, from which only two points, those of traverses C and J, depart in any marked degree. The average change in vertical magnetic intensity per degree of latitude was 942 gammas. Considering the Florida Peninsula as a portion of a sphere with values of magnetism forming a sine function of the latitude, the change due to changing magnetic latitude would be about 450 gammas per degree of latitude. This leaves a difference of 492 gammas which may be assigned to regional effects of large geological features in the general area of which the Florida Peninsula is only a part.

From the relief map it is seen that longitude corrections are more or less meaningless owing to the difficulty of determining a norm or fundamental basis of correction. Most of the longitude change is due to regional geological effects.





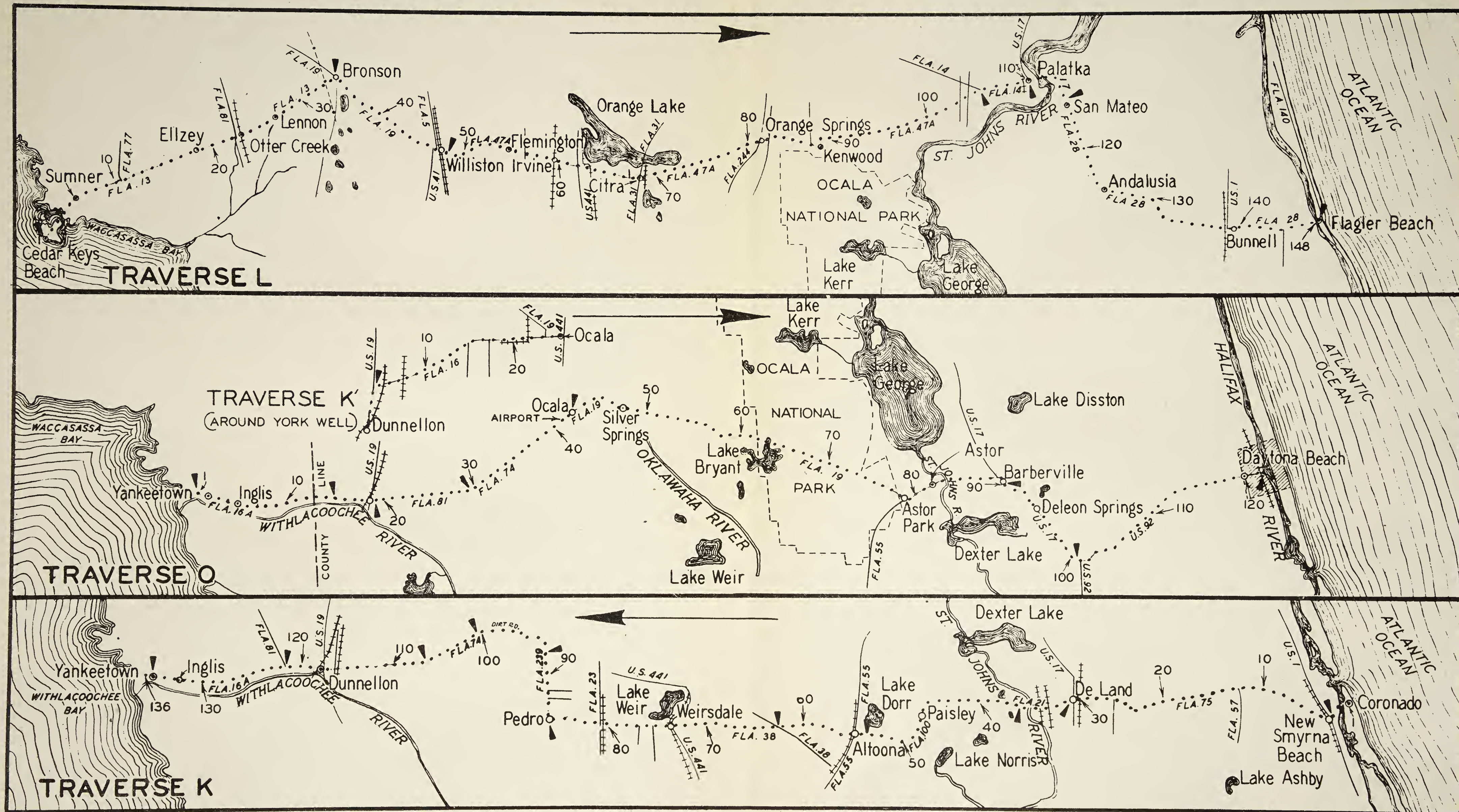
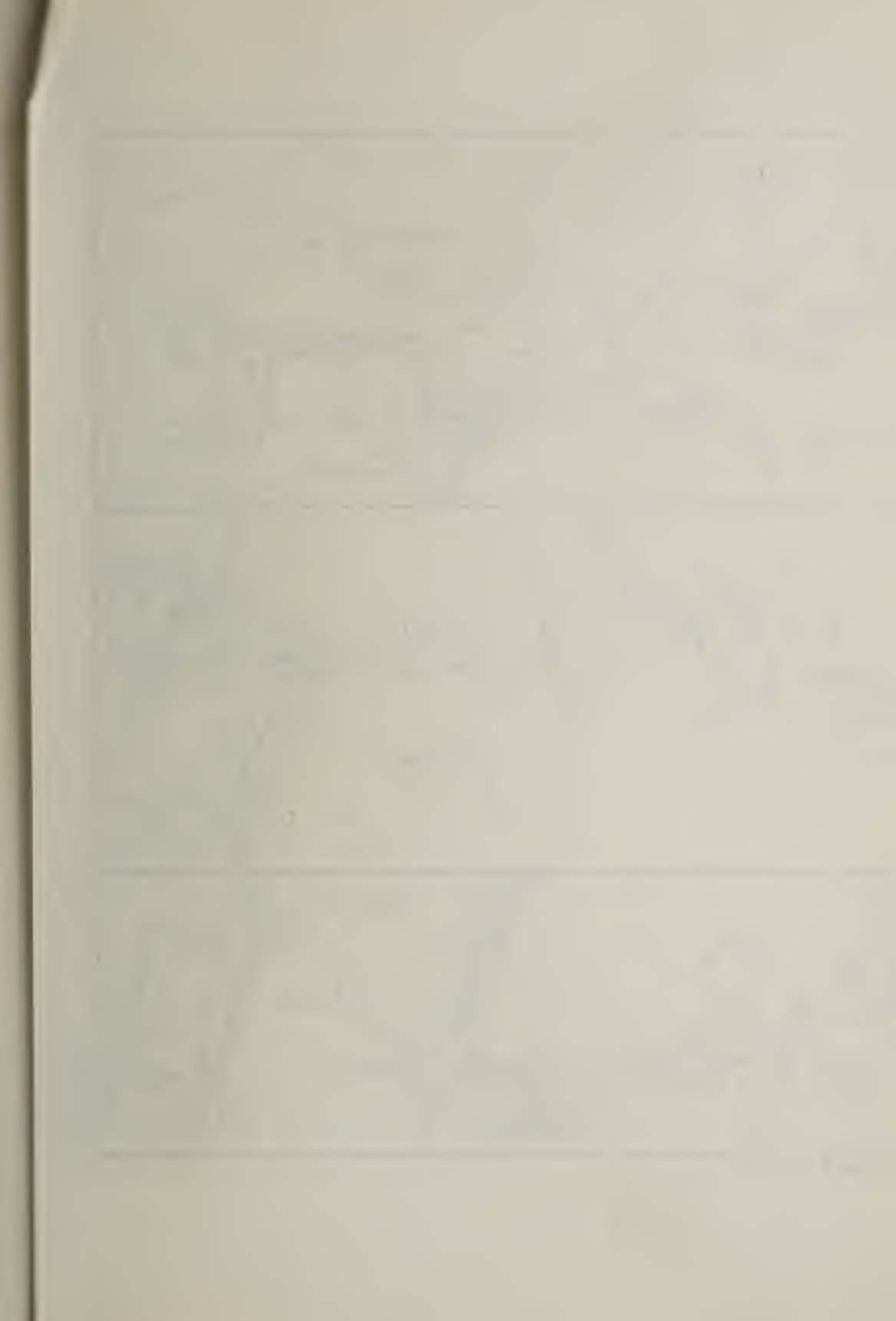


FIGURE 7.- TRAVERSE CHARTS OF K, K', L, AND O.



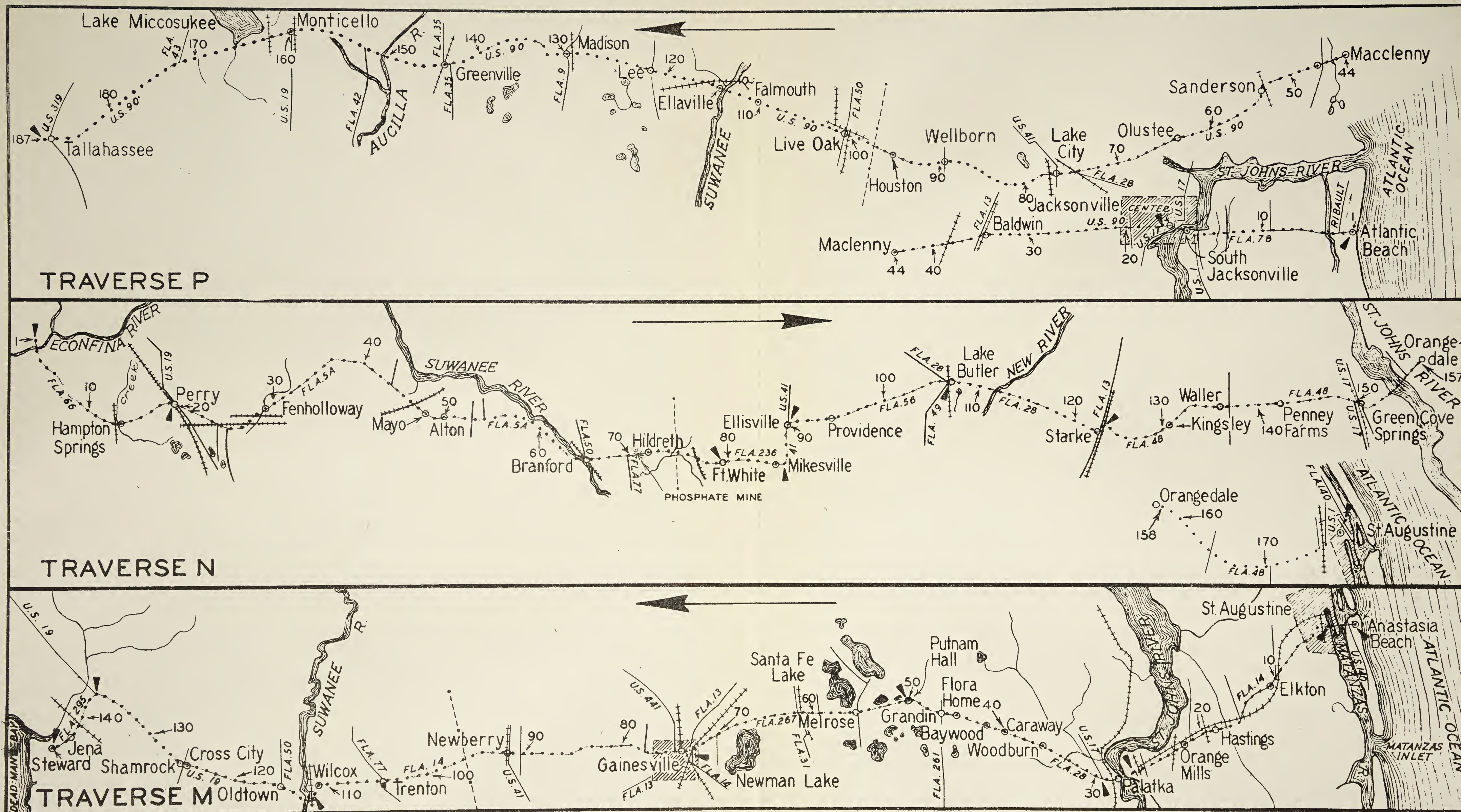


FIGURE 8.- TRAVERSE CHARTS OF M, N, AND P

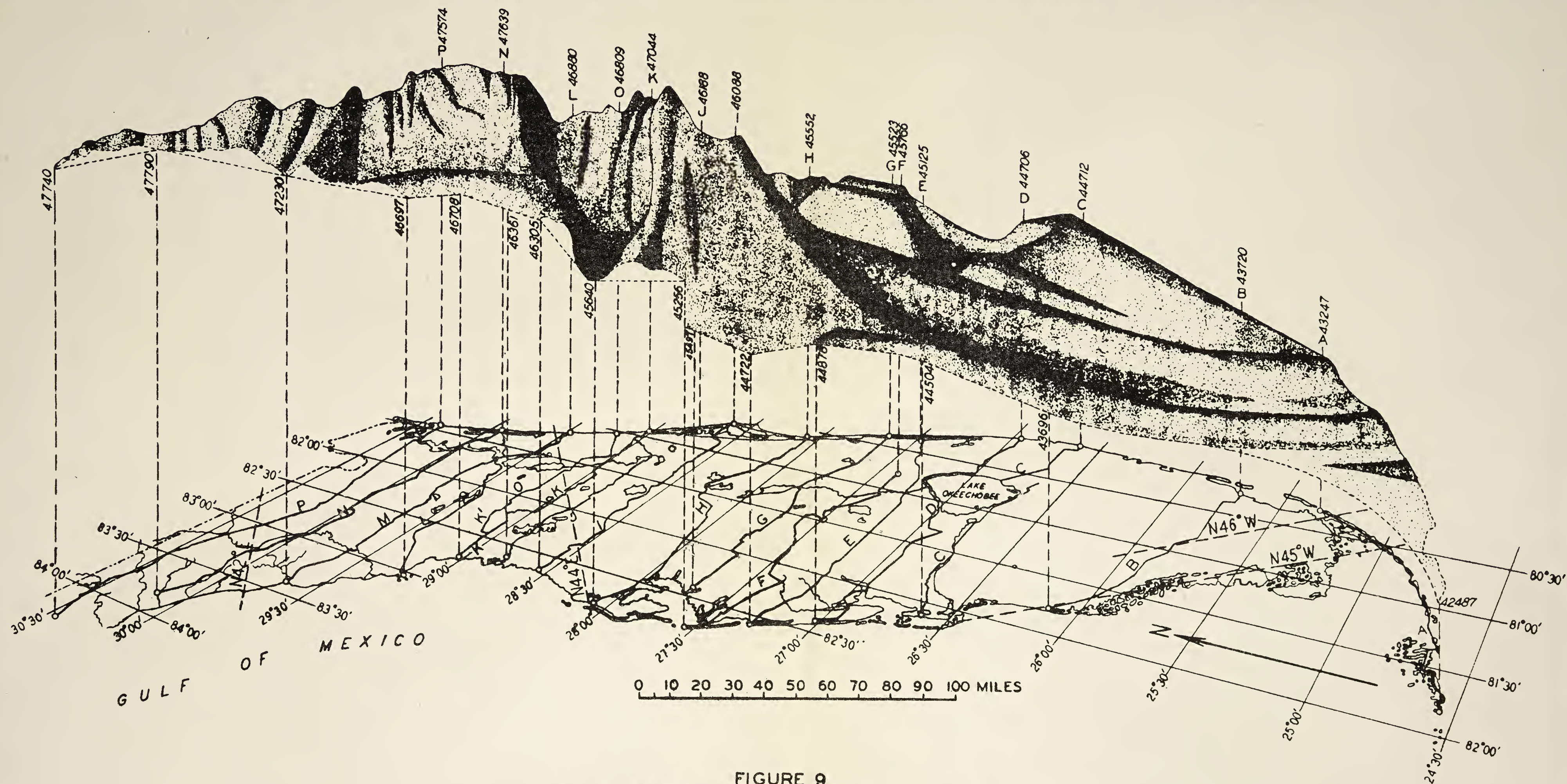


FIGURE 9
FLORIDA PENINSULA MAGNETIC RELIEF MAP

To the best knowledge and belief of the authors the following information was first determined by this magnetic survey:

1. The lower part of the peninsula is geologically a portion of the Antillean trend.
2. The upper portion of the peninsula is geologically a part of the Appalachian system.
3. The folds of the two systems are almost at right angles to each other.
4. There is a zone of considerable structural disturbance across the narrow part of the peninsula which may be to some degree reflected in the Gulf of Mexico coast line.
5. Lake Okeechobee may not be a purely surficial condition, since it is coincident with a strong magnetic low in the crystalline basement.
6. The magnetic values decrease both to the west and the south throughout the peninsula by an amount in excess of that due to the change in magnetic latitude, which indicates that the crystalline basement as a whole is plunging to the southwest in this area.

CONCLUSIONS

- A. Magnetic surveys over large areas have a definite usefulness in providing a knowledge of the geology and the structural and topographic features of the crystalline basement, as well as of overlying structures which reflect them. Such surveys give information concerning orogeny and general features of continental structure, as well as of zones of weakness, shear zones, faults, igneous bodies, and other features of smaller size in the area surveyed.
- B. They are economically important, especially in undeveloped regions and areas, since they form a basis for mineral exploration and the search for petroleum and other natural resources.
- C. Magnetic surveys can be accurately made at a lower cost and can cover large areas more quickly than any other type of geophysical survey.
- D. Because of its speed, its economy, and the amount of information which it yields, a magnetic survey is the logical start in undertaking geological surveys of large areas, especially in regions devoid of outcrops.

E. Much time can be saved in conducting magnetic surveys by a proper selection and the absolute measurement of base stations as tie-in points.

F. There is needed a means for quickly determining the absolute magnetic value at such base stations. Such an instrument is in process of development by the Division of Geophysical Exploration of the Bureau of Mines.

Florida magnetic traverse A

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|---|-------------------|----------------|-----------------------------|-------|-------------|----------------|-----------------------------|
| Traverse A started at northern tip of Key Largo | | | | 27 | 4A | 28 | 901 |
| 0 | Dirt road | 1 | 43247 | 28 | Tavernier | 29 | 842 |
| 1 | do. | 2 | 265 | 29 | 4A | 30 | 885 |
| 2 | do. | 3 | 252 | 30 | do. | 31 | 880 |
| 3 | do. | 4 | 294 | 31 | do. | 32 | 879 |
| 4 | do. | 5 | 289 | 32 | do. | 33 | 42869 |
| 4.8 | Road junction | 4A | | 33 | do. | 34 | 857 |
| 5 | 4A | 6 | 291 | 34 | do. | 35 | 864 |
| 6 | do. | 7 | 252 | 35 | do. | 36 | 861 |
| 7 | do. | 8 | 218 | 36 | do. | 37 | 847 |
| 8 | do. | 9 | 167 | 36.8 | Islamorada | | |
| 9 | do. | 10 | 101 | 37 | 4A | 38 | 808 |
| 10 | do. | 11 | 024 | 38 | do. | 39 | 767 |
| 11 | do. | 12 | 42992 | 39 | do. | 40 | 773 |
| 12 | do. | 13 | 955 | 40 | do. | 41 | 740 |
| 13 | do. | 14 | 926 | 41 | do. | 42 | 732 |
| 14 | do. | 15 | 905 | 42.3 | do. | 43 | 718 |
| 14 | Key Largo Station | | | 43 | do. | 44 | 691 |
| 15 | 4A | 16 | 894 | 44 | do. | 45 | 692 |
| 16 | do. | 17 | 890 | 45 | do. | 46 | 716 |
| 17 | do. | 18 | 887 | 45.8 | Toll gate | | |
| 18 | do. | 19 | 866 | 46 | do. | 47 | 696 |
| 19 | do. | 20 | 868 | 47 | do. | 48 | 696 |
| 20 | do. | 21 | 864 | 48 | do. | 49 | 697 |
| 21 | do. | 22 | 862 | 49 | Bridge | | |
| 21.7 | Rock Harbor | | | 50 | 4A | 50 | 697 |
| 22 | 4A | 23 | 864 | 50 | On Long Key | | |
| 23 | do. | 24 | 871 | 51 | 4A | 51 | 698 |
| 24 | do. | 25 | 881 | 52 | do. | 52 | 690 |
| 25 | do. | 26 | 877 | 53 | do. | 53 | 663 |
| 26 | do. | 27 | 892 | | | | |

Florida magnetic traverse A (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|--------------|---------------------|----------------|-----------------------------|-------|--|----------------|-----------------------------|
| 54 | 4A | 54 | 637 | 95.2 | Little Torch Key | 77A | 665 |
| 55 | On bridge | | | 96.7 | 4A | 78A | 649 |
| 56 | do. | | | 96.7 | Ramrod Key | | |
| 57 | do. | | | 97.7 | On bridge | | |
| 57.6 | | 55 | 608 | 98.7 | 4A | 79A | 635 |
| 58 | Fill and bridge | | | 99.7 | 4A | 80A | 632 |
| 59 | do. | | | 99.7 | Summerland Key | | |
| 60 | do. | | | 101.2 | 4A | 81A | 623 |
| 60.5 | | 56 | 571 | 102.7 | do. | 82A | 611 |
| 61.4 | | 57 | 573 | 104.2 | do. | 83A | 604 |
| 62.5 | | 58 | 42566 | 105.7 | do. | 84A | 42586 |
| 64 | | 59 | 565 | 107.2 | do. | 85A | 582 |
| 65 | 4A | 60 | 539 | 108.7 | do. | 86A | 558 |
| 66 | do. | 61 | 587 | 110.2 | do. | 87A | 581 |
| 67 | do. | 62 | 590 | 111.7 | do. | 88A | 569 |
| 67 | Bone Fish Key | | | 113.2 | do. | 89A | 566 |
| 68.5 | 4A | 63 | 609 | 114.7 | do. | 90A | 564 |
| 70 | do. | 64 | 612 | 116.2 | do. | 91A | 565 |
| 71.5 | do. | 65 | 628 | 117.7 | do. | 92A | 562 |
| 72.8 | Marathon Store | | | 118.7 | do. | 93A | 548 |
| 73 | 4A | 66 | 665 | 119.7 | do. | 94A | 554 |
| 73.7 to 80.7 | Bridge | | | 120.7 | do. | 95A | 542 |
| 75.8 | Pigeon Key | | | 121.7 | do. | 96A | 479 |
| 81 | 4A | 67 | 692 | 121.7 | West end of bridge | | |
| 82 | do. | 68 | 682 | 122.7 | 4A | 97A | 546 |
| 83.5 | do. | 69 | 678 | 123.6 | do. | 98A | 526 |
| 84.5 | do. | 70 | 657 | 125.5 | do. | 99A | 527 |
| 86 | do. | 71 | 649 | 127.7 | do. | 100A | 487 |
| 86 | West Summerland Key | | | 127.7 | Baseball grounds, Naval Reservation near radio station; traverse ended at Key West | | |
| 88 | 4A | 72 | 639 | | | | |
| 89.5 | do. | 73 | 659 | | | | |
| 90.7 | do. | 74A | 660 | | | | |
| 92.2 | do. | 75A | 688 | | | | |
| 93.7 | do. | 76A | 665 | | | | |
| 93.7 | West end of bridge | | | | | | |

Florida magnetic traverse B

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|-----------------------|----------------|-----------------------------|
| 0 | Beach S. Miami | 1 | 43720 | 28 | U.S. 94 | 29 | 43749 |
| 1 | Sunset Drive | 2 | 707 | 29 | do. | 30 | 746 |
| 2 | Opp. School | 3 | 701 | 30 | do. | 31 | 743 |
| 3 | South Miami | 4 | 706 | 31 | do. | 32 | 757 |
| 3.9 | R.R. crossing | | | 32 | do. | 33 | 769 |
| 4 | | 5 | 712 | 33 | do. | 34 | 758 |
| 5 | | 6 | 707 | 34 | do. | 35 | 774 |
| 5.9 | R.R. crossing | | | 35 | do. | 36 | 784 |
| 6 | | 7 | 711 | 36 | do. | 37 | 780 |
| 7 | | 8 | 702 | 37 | do. | 38 | 794 |
| 7.5 | Traverse swings N.W. on dirt road (Snapper Creek Rd.) | | | 38 | do. | 39 | 777 |
| 8 | do. | 9 | 706 | 39 | do. | 40 | 762 |
| 9 | do. | 10 | 725 | 40 | do. | 41 | 754 |
| 10 | do. | 11 | 745 | 40.3 | Oasis road turns here | | |
| 11 | do. | 12 | 743 | 41 | U.S. 94 | 42 | 753 |
| 12 | do. | 13 | 770 | 42 | do. | 43 | 748 |
| 12 | Heavy fill; along drainage canal | | | 43 | do. | 44 | 774 |
| 12.4 | West on U.S. 94, Tamiami Trail | | | 44 | do. | 45 | 787 |
| 13 | U.S. 94 | 14 | 758 | 45 | do. | 46 | 803 |
| 14 | do. | 15 | 762 | 46 | Paolita | 47 | 809 |
| 15 | do. | 16 | 762 | 47 | U.S. 94 | 48 | 832 |
| 16 | do. | 17 | 749 | 48 | do. | 49 | 829 |
| 17 | do. | 18 | 747 | 48.6 | Road turns left | | |
| 18 | do. | 19 | 725 | 49 | U.S. 94 | 50 | 814 |
| 18.5 | Route Fla. 205 goes South | | | 50 | do. | 51 | 791 |
| 19 | U.S. 94 | 20 | 741 | 51 | do. | 52 | 771 |
| 20 | do. | 21 | 744 | 52 | do. | 53 | 741 |
| 21 | do. | 22 | 744 | 53 | do. | 54 | 715 |
| 22 | do. | 23 | 751 | 54 | do. | 55 | 689 |
| 23 | do. | 24 | 753 | 55 | do. | 56 | 643 |
| 24 | do. | 25 | 753 | 56 | do. | 57 | 605 |
| 25 | do. | 26 | 736 | 57 | do. | 58 | 580 |
| 26 | do. | 27 | 747 | 58 | do. | 59 | 547 |
| 27 | do. | 28 | 745 | 59 | do. | 60 | 523 |
| | | | | 60 | do. | 61 | 504 |

Florida magnetic traverse B (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-------------------------|----------------|-----------------------------|-------|------------------------------------|----------------|-----------------------------|
| 61 | U.S. 94 | 62 | 43477 | 90 | U.S. 94 | 90 | 727 |
| 62 | do. | 63 | 466 | 91 | do. | 91 | 740 |
| 63 | do. | 64 | 450 | 92 | do. | 92 | 754 |
| 64 | do. | 65 | 441 | 93 | do. | 93 | 768 |
| 65 | do. | 66 | 424 | 93.5 | Road goes off south to Marco Beach | | |
| 66 | do. | 67 | 402 | 94 | U.S. 94 | 94 | 43763 |
| 67 | do. | 68 | 410 | 95 | | 95 | 764 |
| 68 | do. | 69 | 407 | 96 | do. | 96 | 776 |
| 69 | do. | 70 | 419 | 97 | do. | 97 | 766 |
| 70 | do. | 71 | 428 | 98 | do. | 98 | 766 |
| 71 | do. | 72 | 434 | 99 | do. | 99 | 762 |
| 72 | do. | 73 | 441 | 100 | do. | 100 | 754 |
| 73 | In Ochopee | 74 | 431 | 101 | do. | 101 | 744 |
| 74 | U.S. 94 | 75 | 481 | 102 | do. | 102 | 736 |
| 75 | do. | 76 | 501 | 103 | do. | 103 | 729 |
| 76 | do. | 77 | 511 | 104 | do. | 104 | 729 |
| 77.5 | do. | 78 | 509 | 105 | do. | 105 | 720 |
| 77.5 | Road junction, Fla. 164 | | | 106 | do. | 106 | 712 |
| 78 | R.R. crossing | | | 107 | do. | 107 | 701 |
| 79 | U.S. 94 | 79 | 532 | 108 | do. | 108 | 704 |
| 80 | do. | 80 | 535 | 109 | do. | 109 | 692 |
| 81 | do. | 81 | 535 | 109.9 | R.R. crossing | | |
| 82 | do. | 82 | 568 | 110 | U.S. 41 turns north | | |
| 83 | do. | 83 | 578 | 110.2 | U.S. 94 | 110 | 670 |
| 84 | do. | 84 | 604 | 111 | do. | 111 | 696 |
| 85 | do. | 85 | 622 | 111 | On beach, Naples, Fla. | | |
| 86 | do. | 86 | 652 | | | | |
| 87 | do. | 87 | 683 | | | | |
| 88 | do. | 88 | 698 | | | | |
| 89 | do. | 89 | 711 | | | | |

Florida magnetic traverse C

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|---|-------------------------|----------------|-----------------------------|-------|--------------------------------|----------------|-----------------------------|
| Traverse C starts at Pine Island Sound west of Fort Myers at west of Fla. 183 | | | | | | | |
| 0 | Fla. 183 | 1 | 44504 | 26.5 | Paved road | | |
| 1 | do. | 2 | 540 | 27 | Fla. 292 | 28 | 44530 |
| 2 | do. | 3 | 513 | 28 | do. | 29 | 494 |
| 3 | Small bridge | 4 | 478 | 29 | do. | 30 | 515 |
| 3.4 | Large bridge | | | 30 | do. | 31 | 503 |
| 4 | Fla. 183 | 5 | 539 | 30 | Road turns sharp left | | |
| 5 | do. | 6 | 513 | 31 | Fla. 292 | 32 | 524 |
| 6 | do. | 7 | 516 | 32 | do. | 33 | 530 |
| 7 | do. | 8 | 500 | 33 | do. | 34 | 533 |
| 8 | do. | 9 | 539 | 34 | do. | 35 | 559 |
| 9 | do. | 10 | 521 | 35 | do. | 36 | 526 |
| 10 | do. | 11 | 517 | 35.9 | Road turned SE. | | |
| 11 | do. | 12 | 518 | 36 | Fla. 292 | 37 | 591 |
| 12 | do. | 13 | 535 | 36.7 | Road turned south | | |
| 13 | do. | 14 | 538 | 37 | In Alva, Fla. 25/38 | | 525 |
| 14 | do. | 15 | 540 | 37.5 | Turned left, Fla. 25 | | |
| 14.5 | Small creek | | | 38 | Fla. 25 | 39 | 567 |
| 15 | Fla. 183 | 16 | 522 | 39 | do. | 40 | 610 |
| 16 | do. | 17 | 484 | 40 | do. | 41 | 628 |
| 16.2 | Junction U.S. | 41 | | | | | |
| 16.7 | R.R. crossing | | | 41 | do. | 42 | 697 |
| 17 | Fla. 183 | 18 | 477 | 42 | do. | 43 | 741 |
| 18 | do. | 19 | 472 | 43 | do. | 44 | 770 |
| 18.4 | Road to north | | | 43 | R.R. comes in parallel to road | | |
| 19 | Fla. 183 | 20 | 485 | 44 | Fla. 25 | 45 | 829 |
| 20 | do. | 21 | 482 | 45 | do. | 46 | 898 |
| 20 | Doughtrey Dairy | | | 46 | do. | 47 | 969 |
| 20.8 | Bay Shore | | | 47 | do. | 48 | 45008 |
| 21 | Fla. 183 | 22 | 466 | 47.2 | Road swings away from R.R. | | |
| 22 | do. | 23 | 459 | 48 | Fla. 25 | 49 | 042 |
| 23 | do. | 24 | 503 | 49 | do. | 50 | 063 |
| 24 | do. | 25 | 444 | 49.9 | Labelle | | |
| 25 | do. | 26 | 497 | 50 | Fla. 25 | 51 | 039 |
| 25.2 | Road jogs north to 26.2 | | | 51 | do. | 52 | 036 |
| 26 | Fla. 183 | 27 | 505 | 52 | do. | 53 | 010 |

Florida magnetic traverse C (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--------------------|----------------|-----------------------------|-------|--------------------------------------|----------------|-----------------------------|
| 53 | Fla. 25 | 54 | 45024 | 85 | Fla. 25 | 86 | 44902 |
| 54 | do. | 55 | 034 | 86 | do. | 87 | 881 |
| 55 | do. | 56 | 014 | 87 | do. | 88 | 831 |
| 56 | do. | 57 | 44990 | 88 | do. | 89 | 840 |
| 57 | do. | 58 | 984 | 89 | do. | 90 | 838 |
| 58 | do. | 59 | 965 | 89 | Filled-in ground | | |
| 59 | do. | 60 | 934 | 90 | Fla. 25 | 91 | 850 |
| 60 | do. | 61 | 934 | 91 | do. | 92 | 805 |
| 61 | do. | 62 | 926 | 92 | do. | 93 | 839 |
| 62 | do. | 63 | 922 | 93 | do. | 94 | 812 |
| 63 | do. | 64 | 963 | 94 | do. | 95 | 823 |
| 64 | do. | 65 | 994 | 95 | do. | 96 | 851 |
| 65 | do. | 66 | 45018 | 96 | do. | 97 | 784 |
| 66 | do. | 67 | 038 | 97 | do. | 98 | 693 |
| 67 | do. | 68 | 033 | 97.4 | R.R. tracks, South Bay | | |
| 68 | do. | 69 | 020 | 98 | Fla. 25 | 99 | 779 |
| 69 | do. | 70 | 028 | 99 | do. | 100 | 777 |
| 70 | do. | 71 | 45015 | 100 | do. | 101 | 779 |
| 71 | do. | 72 | 027 | 100.4 | Road turns north | | |
| 72 | do. | 73 | 012 | 101 | | 102 | 770 |
| 73 | do. | 74 | 032 | 102 | | 103 | 711 |
| 74 | do. | 75 | 018 | 102 | Highway 143 joins from north | | |
| 75 | do. | 76 | 001 | 103 | Fla. 25 | 104 | 748 |
| 76 | do. | 77 | 44991 | 104 | do. | 105 | 733 |
| 77 | do. | 78 | 979 | 105 | do. | 106 | 778 |
| 78 | do. | 79 | 982 | 106 | do. | 107 | 763 |
| 79 | do. | 80 | 974 | 107 | do. | 108 | 773 |
| 80 | do. | 81 | 945 | 108 | do. | 109 | 765 |
| 81 | do. | 82 | 945 | 108 | Road closed; returned to Canal Point | | |
| 81 | Entering Clewiston | | | | | | |
| 82 | | 83 | 925 | 0 | At Canal Point, new starting point | | |
| 82 | Leaving Clewiston | | | 0 | Fla. 194 | 110 | 745 |
| 82.5 | R.R. tracks | | | 1 | do. | 111 | 782 |
| 83 | Fla. 25 | 84 | 912 | 2 | do. | 112 | 755 |
| 84 | do. | 85 | 901 | 3 | do. | 113 | 779 |

Florida magnetic traverse C (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|-------|---------------------|--------------------|-----------------------------|
| 4 | Fla. 194 | 114 | 44782 | 29 | Fla. 25 | 139 | 762 |
| 5 | do. | 115 | 776 | 30 | do. | 140 | 764 |
| 6 | do. | 116 | 767 | 31 | do. | 141 | 829 |
| 7 | do. | 117 | 760 | 31.2 | Intersection | Route 199, Fla. 25 | |
| 8 | do. | 118 | 751 | 32 | | 142 | 848 |
| 9 | do. | 119 | 739 | 33 | do. | 143 | 857 |
| 10 | do. | 120 | 724 | 34 | do. | 144 | 886 |
| 11 | do. | 121 | 711 | 35 | do. | 145 | 884 |
| 12 | do. | 122 | 692 | 36 | do. | 146 | 896 |
| 13 | do. | 123 | 684 | 37 | do. | 147 | 872 |
| 14 | do. | 124 | 687 | 38 | Fla. 25 | 148 | 44860 |
| 15 | do. | 125 | 714 | 39 | do. | 149 | 853 |
| 16 | do. | 126 | 693 | 40 | do. | 150 | 824 |
| 17 | do. | 127 | 700 | 40.8 | Sharp left turn | | |
| 18 | do. | 128 | 710 | 41 | | 151 | 821 |
| 19 | do. | 129 | 711 | 42 | | 152 | 813 |
| 19.3 | Route Fla. 194 intersection with Fla. 25 | | | 43 | | 153 | 821 |
| 20 | Fla. 25 | 130 | 713 | 43.5 | R.R. crossing | | |
| 21 | do. | 131 | 696 | 44 | | 154 | 795 |
| 22 | do. | 132 | 712 | 44.2 | R. R. crossing | | |
| 23 | do. | 133 | 716 | 45 | | 155 | 728 |
| 24 | do. | 134 | 742 | 45 | Edge of first water | | |
| 25 | do. | 135 | 724 | 45.7 | | 156 | 712 |
| 26 | do. | 136 | 734 | | | | |
| 26.6 | Canal at Loxahatchee | | | | | | |
| 27 | Fla. 25 | 137 | 734 | | | | |
| 28 | do. | 138 | 744 | | | | |

Florida magnetic traverse D

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|---------------------------------|--------------------|----------------|-----------------------------|-------|----------|----------------|-----------------------------|
| Traverse D started at Englewood | | | | | | | |
| 0 | | 1 | 44878 | 4 | Fla. 181 | 5 | 967 |
| 1 | | 2 | 891 | 5 | do. | 6 | 974 |
| 2 | | 3 | 930 | 6 | do. | 7 | 977 |
| 2.3 | Junction 173 & 181 | | | 7 | do. | 8 | 974 |
| 3 | Fla. 181 | 4 | 911 | 8 | do. | 9 | 956 |

Florida magnetic traverse D (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------------------------------|----------------|-----------------------------|-------|---|----------------|-----------------------------|
| 9 | Fla. 181 | 10 | 933 | 37 | Fla. 262 | 38 | 838 |
| 9.7 | R.R. & road turns | | | 38 | do. | 39 | 822 |
| 10 | | 11 | 911 | 39 | do. | 40 | 793 |
| 11 | Fla. 181 | 12 | 916 | 40 | do. | 41 | 771 |
| 11 | Stations 11, 12 & 13 parallel to R.R. | | | 41 | do. | 42 | 770 |
| 12 | Fla. 181 | 13 | 902 | 42 | do. | 43 | 772 |
| 13 | do. | 14 | 896 | 43 | do. | 44 | 771 |
| 14 | do. | 15 | 866 | 44 | do. | 45 | 776 |
| 15 | do. | 16 | 850 | 45 | Intersection Fla. 2 & 262 | | |
| 16 | do. | 17 | 788 | 45 | Fla. 262 | 46 | 804 |
| 17 | do. | 18 | 722 | 46 | do. | 47 | 835 |
| 17.9 | Junction U.S. 41 & Fla. 181 | | | 47 | do. | 48 | 844 |
| 18 | | 19 | 699 | 47 | (This road was merely a trail from Bermont to Hall city, which is south of Palmdale. Mileage may be a little off due to deep, loose sand) | | |
| 19 | | 20 | 696 | | | | |
| 20 | U.S. 41 | 21 | 707 | | | | |
| 21 | do. | 22 | 725 | | | | |
| 22 | do. | 23 | 728 | 48 | Trail | 49 | 860 |
| 23 | do. | 24 | 759 | 49 | do. | 50 | 870 |
| 24 | do. | 25 | 708 | 50 | do. | 51 | 868 |
| 25 | Edge of bay | 26 | 762 | 51 | do. | 52 | 876 |
| 26 | | 27 | 762 | 52 | do. | 53 | 887 |
| 26 | E. side bridge, entering Punta Gorda | | | 53 | do. | 54 | 898 |
| 26.3 | Jct. U.S. 41 & 17 | | | 54 | do. | 55 | 899 |
| 27 | U.S. 17 | 28 | 776 | 55 | do. | 56 | 909 |
| 28 | do. | 29 | 788 | 56 | do. | 57 | 908 |
| 29 | do. | 30 | 44827 | 57 | do. | 58 | 866 |
| 29.8 | Junction U.S. 17 & Fla. 262 | | | 58 | do. | 59 | 44877 |
| 30 | Fla. 262 | 31 | 835 | 59 | do. | 60 | 888 |
| 31 | do. | 32 | 847 | 60 | do. | 61 | 883 |
| 32 | do. | 33 | 871 | 61 | do. | 62 | 881 |
| 33 | do. | 34 | 887 | 62 | do. | 63 | 873 |
| 34 | do. | 35 | 887 | 63 | do. | 64 | 889 |
| 34.3 | R.R. crossing | | | 64 | do. | 65 | 883 |
| 35 | Fla. 262 | 36 | 868 | 65 | do. | 66 | 877 |
| 36 | do. | 37 | 844 | 66 | do. | 67 | 869 |
| | | | | 67 | do. | 68 | 867 |

Florida magnetic traverse D (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|-----------------------------|----------------|-----------------------------|
| 68 | Trail | 69 | 867 | 94 | | 95 | 794 |
| 69 | do. | 70 | 863 | 95 | | 96 | 770 |
| 70 | do. | 71 | 854 | 96 | | 97 | 739 |
| 71 | do. | 72 | 835 | 97 | Fla. 29 | 98 | 708 |
| 72 | do. | 73 | 842 | 98 | Filled ground | 99 | 654 |
| 73 | do. | 74 | 859 | 99 | do. | 100 | 647 |
| 74 | do. | 75 | 864 | 100 | do. | 101 | 607 |
| 74.1 | Turned north toward Palmdale | | | 101 | do. | 102 | 594 |
| 74.3 | Miles R.R. crossing at Hall City | | | 102 | do. | 103 | 548 |
| 75 | | 76 | 856 | 103 | do. | 104 | 502 |
| 75 | Going north toward Palmdale | | | 104 | do. | 105 | 486 |
| 76 | | 77 | 856 | 105 | do. | 106 | 482 |
| 77 | | 78 | 860 | 106 | do. | 107 | 497 |
| 77.8 | R.R. crossing | | | 107 | do. | 108 | 517 |
| 78 | | 79 | 857 | 108 | do. | 109 | 537 |
| 78 | Turned off on surfaced road; about 1 mile south of Palmdale | | | 109 | do. | 110 | 560 |
| 79 | | 80 | 837 | 110 | do. | 111 | 581 |
| 79 | Entering Palmdale | | | 111 | do. | 112 | 603 |
| 79.2 | Turned right in Palmdale heading toward Lakeport | | | 112 | do. | 113 | 621 |
| 80 | | 81 | 877 | 113 | do. | 114 | 636 |
| 81 | | 82 | 893 | 114 | Filled ground | 115 | 620 |
| 82 | | 83 | 894 | 114.2 | Kissimmee River | | |
| 83 | | 84 | 880 | 114.3 | Fla. 29 pavement | | |
| 84 | | 85 | 901 | 115 | Fla. 29 | 116 | 643 |
| 84.1 | Crossed bridge over dry creek | | | 116 | Filled ground | 117 | 675 |
| 85 | | 86 | 44926 | 117 | Fla. 29 | 118 | 44687 |
| 86 | | 87 | 934 | 118 | do. | 119 | 719 |
| 87 | | 88 | 905 | 119 | Junction Fla. 29 & Fla. 194 | | |
| 88 | | 89 | 884 | 119 | | 120 | 730 |
| 89 | | 90 | 857 | 120 | Fla. 194 | 121 | 739 |
| 90 | | 91 | 849 | 121 | do. | 122 | 775 |
| 91 | | 92 | 846 | 122 | do. | 123 | 737 |
| 92 | | 93 | 833 | 123 | do. | 124 | 746 |
| 93 | In Lakeport | 94 | 835 | 124 | do. | 125 | 741 |
| | | | | 125 | do. | 126 | 716 |

Florida magnetic traverse D (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|------------------------|----------------|-----------------------------|-------|---|----------------|-----------------------------|
| 126 | Fla. 194 | 127 | 737 | 155 | Fla. 29 | 156 | 452 |
| 127 | Filled ground | 128 | 717 | 156 | do. | 157 | 480 |
| 128 | do. | 129 | 682 | 157 | do. | 158 | 493 |
| 129 | do. | 130 | 647 | 158 | do. | 159 | 506 |
| 130 | do. | 131 | 618 | 159 | do. | 160 | 517 |
| 131 | Solid ground | 132 | 594 | 160 | do. | 161 | 521 |
| 132 | Filled ground | 133 | 576 | 161 | do. | 162 | 536 |
| 133 | Solid ground | 134 | 537 | 162 | do. | 163 | 531 |
| 134 | do. | 135 | 509 | 163 | do. | 164 | 542 |
| 135 | do. | 136 | 478 | 164 | do. | 165 | 536 |
| 136 | do. | 137 | 446 | 165 | do. | 166 | 542 |
| 137 | do. | 138 | 439 | 166 | do. | 167 | 552 |
| 138 | do. | 139 | 438 | 167 | do. | 168 | 548 |
| 139 | do. | 140 | 443 | 168 | do. | 169 | 552 |
| 140 | Filled ground | 141 | 438 | 169 | do. | 170 | 559 |
| 141 | do. | 142 | 445 | 170 | do. | 171 | 565 |
| 141.7 | Junction of 194 & 109 | | | 170.3 | Side road enters highway from SW. | | |
| 142 | Fla. 109 | 143 | 471 | 171 | Fla. 29 | 172 | 578 |
| 142.4 | R.R. crossing | | | 172 | do. | 173 | 600 |
| 143 | Fla. 109 | 144 | 487 | 173 | do. | 174 | 618 |
| 144 | do. | 145 | 470 | 174 | do. | 175 | 640 |
| 145 | do. | 146 | 501 | 175 | do. | 176 | 669 |
| 146 | do. | 147 | 485 | 176 | do. | 177 | 692 |
| 147 | do. | 148 | 490 | 176.9 | Junction Fla. 29 & old Fla. 1, now Fla. 176, & R.R. | | |
| 148 | do. | 149 | 496 | 177 | Fla. 29 | 178 | 44691 |
| 149 | Fla. 109 | 150 | 44481 | 177.8 | Junction Fla. 140, 176, 29 & U.S. 1 | | |
| 150 | do. | 151 | 476 | 178 | Jupiter | 179 | 703 |
| 151 | do. | 152 | 457 | 178.6 | | 180 | 706 |
| 152 | do. | 153 | 464 | 178.6 | On beach east of Jupiter | | |
| 152.5 | R.R. crossing | | | | | | |
| 152.8 | Junction Fla. 109 & 85 | | | | | | |
| 153 | | 154 | 477 | | | | |
| 153.4 | Junction Fla. 109 & 29 | | | | | | |
| 154 | Fla. 29 | 155 | 449 | | | | |

Florida magnetic traverse E

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|----------------------------------|----------------|-----------------------------|-------|------------------------------------|----------------|-----------------------------|
| 0.0 | U.S. 1 and Fla. 8 in Fort Pierce | | | 34 | Fla. 8 | 34 | 811 |
| 0.6 | In school grounds | 1 | 45125 | 35 | do. | 35 | 44802 |
| 2 | Fla. 8 | 2 | 122 | 35.5 | R.R. crossing | | |
| 3 | do. | 3 | 078 | 35.6 | Junction Fla. 8 & 85 | | |
| 4 | do. | 4 | 071 | 36 | Fla. 8 | 36 | 796 |
| 4.1 | Road intersection | | | 36 | Okeechobee city limits | | |
| 5 | Fla. 8 | 5 | 054 | 36.9 | Junction Fla. 8 & Fla. 29 | | |
| 6 | do. | 6 | 046 | 37 | Middle of town parkway | | |
| 7 | do. | 7 | 054 | 37 | | 37 | 792 |
| 8 | do. | 8 | 066 | 37.4 | R.R. crossing west edge Okeechobee | | |
| 9 | do. | 9 | 060 | 38 | Fla. 8 | 38 | 800 |
| 10 | do. | 10 | 069 | 39 | do. | 39 | 800 |
| 11 | do. | 11 | 068 | 40 | do. | 40 | 807 |
| 12 | do. | 12 | 053 | 41 | do. | 41 | 809 |
| 13 | do. | 13 | 035 | 42 | do. | 42 | 806 |
| 14 | do. | 14 | 017 | 43 | do. | 43 | 810 |
| 15 | do. | 15 | 022 | 44 | do. | 44 | 806 |
| 16 | do. | 16 | 045 | 45 | do. | 45 | 791 |
| 17 | do. | 17 | 057 | 46 | do. | 46 | 756 |
| 18 | do. | 18 | 060 | 46.6 | Kissimmee River | | |
| 19 | do. | 19 | 041 | 47 | Filled ground | 47 | 695 |
| 20 | do. | 20 | 016 | 48 | do. | 48 | 694 |
| 21 | do. | 21 | 004 | 49 | Fla. 8 | 49 | 697 |
| 22 | do. | 22 | 44978 | 50 | do. | 50 | 714 |
| 23 | do. | 23 | 967 | 51 | do. | 51 | 738 |
| 24 | do. | 24 | 932 | 52 | Fla. 8 | 52 | 44770 |
| 25 | do. | 25 | 907 | 53 | do. | 53 | 798 |
| 26 | do. | 26 | 906 | 53.9 | Junction Fla. 8 & 145 in Brighton | | |
| 27 | do. | 27 | 893 | 54 | Fla. 8 | 54 | 792 |
| 28 | do. | 28 | 874 | 55 | do. | 55 | 792 |
| 29 | do. | 29 | 45850 | 56 | do. | 56 | 802 |
| 30 | do. | 30 | 839 | 57 | do. | 57 | 825 |
| 31 | do. | 31 | 818 | 58 | do. | 58 | 857 |
| 32 | do. | 32 | 818 | 59 | do. | 59 | 899 |
| 33 | do. | 33 | 813 | | | | |

Florida magnetic traverse E (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|-------|------------------------|----------------|-----------------------------|
| 60 | Fla. 8 | 60 | 945 | 95.5 | Side road | | |
| 61 | do. | 61 | .985 | 96 | Fla. 18 | 96 | .999 |
| 62 | do. | 62 | 45009 | 97 | do. | 97 | 45039 |
| 63 | do. | 63 | 037 | 98 | do. | 98 | 067 |
| 64.2 | do. | 64 | .058 | 99 | do. | 99 | 068 |
| 65 | do. | 65 | .070 | 100 | do. | 100 | 086 |
| 66 | | 66 | 088 | 101 | do. | 101 | 076 |
| 66-67 | Distinct elevation rise | | | 101.2 | Junction Fla. 18 & 2 | | |
| 67 | Fla. 8 | 67 | 095 | 102 | | 102 | 039 |
| 68 | do. | 68 | 091 | 102 | Entering Arcadia | | |
| 69 | do. | 69 | .075 | 102.3 | Fla. 18 & U.S. 17 | | |
| 70 | do. | 70 | .056 | 102.4 | R.R. | | |
| 70.1 | R.R. crossing Junction Fla. 67, 8, 18; Fla. 18 Highway | | | 103 | Leaving Arcadia | | |
| 71 | Fla. 18 | 71 | 018 | 103 | | 103 | 058 |
| 72 | do. | 72 | 44990 | 103.5 | R.R. crossing | | |
| 73 | do. | 73 | 957 | 103.8 | Junction Fla. 18 & 220 | | |
| 74 | do. | 74 | .932 | 104 | Fla. 220 | 104 | 095 |
| 75 | do. | 75 | 905 | 105.2 | Side road south | | |
| 74-75 | Distinct elevation drop | | | 105.5 | Fla. 220 | 105 | 087 |
| 76 | Fla. 18 | 76 | 871 | 106 | | 106 | 081 |
| 77 | do. | 77 | 835 | 107 | do. | 107 | 45058 |
| 78 | do. | 78 | 808 | 108 | do. | 108 | 036 |
| 79 | do. | 79 | 778 | 109 | do. | 109 | 019 |
| 80 | do. | 80 | 743 | 110 | do. | 110 | 033 |
| 81 | do. | 81 | 44718 | 110.3 | Side road south | | |
| 82 | do. | 82 | 695 | 111 | Fla. 220 | 111 | 036 |
| 83 | do. | 83 | 676 | 111 | Horse Creek | | |
| 84 | do. | 84 | .663 | 112 | Fla. 220 | 112 | 024 |
| 85 | do. | 85 | 662 | 113 | do. | 113 | 013 |
| 86 | do. | 86 | 665 | 114 | do. | 114 | 44993 |
| 87 | do. | 87 | .683 | 115 | do. | 115 | 966 |
| 88 | do. | 88 | .696 | 116 | do. | 116 | 939 |
| 89 | do. | 89 | 732 | 117 | do. | 117 | 919 |
| 90 | do. | 90 | .775 | 118 | do. | 118 | 879 |
| 91 | do. | 91 | 815 | 119 | do. | 119 | 846 |
| 92 | do. | 92 | 862 | 119.4 | R.R. crossing | | |
| 93 | do. | 93 | 906 | 120 | Fla. 220 | 120 | 815 |
| 94 | do. | 94 | 948 | 121 | do. | 121 | 768 |
| 95 | do. | 95 | 970 | 122 | do. | 122 | 720 |
| | | | | 123 | do. | 123 | 673 |

Florida magnetic traverse E (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-----------------|----------------|-----------------------------|-------|----------------------------|----------------|-----------------------------|
| 124 | Fla. 220 | 124 | 639 | 142 | Fla. 220 | 142 | 44642 |
| 125 | do. | 125 | 622 | 142.4 | Side road north | | |
| 126 | do. | 126 | 606 | 143 | Fla. 220 | 143 | 642 |
| 127 | do. | 127 | 589 | 144 | do. | 144 | 638 |
| 128 | do. | 128 | 577 | 144.3 | Side road south | | |
| 129 | do. | 129 | 569 | 144.4 | R.R. | | |
| 130 | do. | 130 | 561 | 145 | Fla. 220 | 145 | 636 |
| 131 | do. | 131 | 536 | 146 | do. | 146 | 647 |
| 132 | do. | 132 | 536 | 147 | do. | 147 | 634 |
| 132.4 | Myakka River | | | 148 | do. | 148 | 650 |
| 133 | Fla. 220 | 133 | 543 | 148.4 | Junction Fla. 220, U.S. 31 | | |
| 134 | do. | 134 | 547 | 148.6 | Sharp turn to north | | |
| 135 | do. | 135 | 527 | 148.8 | Sharp turn to west | | |
| 136 | do. | 136 | 524 | 149 | | 149 | 667 |
| 137 | do. | 137 | 514 | 149 | 2 miles south of Sarasota | | |
| 138 | do. | 138 | 521 | 150 | Fla. 220 | 150 | 701 |
| 138.9 | Side road south | | | 150 | On Bay Island | | |
| 139 | Fla. 220 | 139 | 548 | 150.6 | | 151 | 722 |
| 140 | do. | 140 | 588 | 150.6 | On Sarasota Beach | | |
| 141 | do. | 141 | 628 | | | | |

Florida magnetic traverse F

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|------------------------|----------------|-----------------------------|-------|------------------------------------|----------------|-----------------------------|
| 0 | On Beach at Anna Maria | | | 13 | Fla. 18a | 13 | 044 |
| 0 | | 1 | 45256 | 13.4 | Junction Fla. 18a & U.S. | 41 | |
| 1 | | 2 | 225 | 14 | Fla. 18a | 14 | 007 |
| 2 | | 3 | 243 | 15 | do. | 15 | 006 |
| 3 | | 4 | 203 | 15.2 | Turned south on hard surfaced road | | |
| 4 | | 5 | 179 | 16 | Fla. 18a | 16 | 44978 |
| 5 | Fla. 18a | 6 | 159 | 16.3 | Oneco; turned east on Fla. 18a | | |
| 5.5 | Road turns east | | | 16.5 | R.R. crossing | | |
| 6.2 | West end Fla. 18a | | | 17 | | 17 | 951 |
| 6.5 | Fla. 18a | 7 | 156 | 17.3 | do. | | |
| 8 | do. | 8 | 133 | 18 | Fla. 18a | 18 | 938 |
| 9 | do. | 9 | 115 | 19 | do. | 19 | 922 |
| 10 | do. | 10 | 100 | 19.3 | River. Beginning of dirt road | | |
| 11 | do. | 11 | 087 | 20 | Fla. 18a | 20 | 915 |
| 12 | do. | 12 | 068 | 21 | do. | 21 | 921 |

Florida magnetic traverse F (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|-------|---|----------------|-----------------------------|
| 22 | Fla. 18a | 22 | 912 | 56 | Fla. 63 | 56 | 45203 |
| 23 | do. | 23 | 893 | 57 | do. | 57 | 247 |
| 24 | do. | 24 | 881 | 58 | do. | 58 | 269 |
| 25 | do. | 25 | 884 | 59 | do. | 59 | 298 |
| 26 | do. | 26 | 899 | 60 | do. | 60 | 322 |
| | | | | 61 | do. | 61 | 333 |
| 27 | do. | 27 | 44888 | | | | |
| 28 | do. | 28 | 881 | 62 | do. | 62 | 354 |
| 29 | do. | 29 | 865 | 63 | do. | 63 | 338 |
| 30 | do. | 30 | 860 | 63.8 | Ona, Fla.; R.R. crossing | | |
| 31 | do. | 31 | 854 | 64 | | 64 | 376 |
| | | | | 65 | Fla. 63 | 65 | 382 |
| 32 | do. | 32 | 864 | | | | |
| 32.2 | Junction Fla. 161 & 18a; paved road | | | 66 | do. | 66 | 367 |
| 33 | Fla. 18a | 33 | 879 | 66.8 | Junction Fla. 302 & begin sand road | | |
| 34 | do. | 34 | 886 | 67 | Fla. 63 | 67 | 345 |
| 34.7 | Verna; junction Fla. 180 | | | 68 | do. | 68 | 328 |
| | | | | | | | |
| 35 | Fla. 18a | 35 | 921 | 69 | do. | 69 | 302 |
| 36 | do. | 36 | 44919 | 70 | do. | 70 | 290 |
| 37 | do. | 37 | 875 | 71 | Pavement begins | 71 | 267 |
| 38 | do. | 38 | 827 | 71.8 | Junction U.S. 17 | | |
| 39 | do. | 39 | 775 | 71.9 | Zolfo Springs | | |
| | | | | | | | |
| 40 | do. | 40 | 747 | 72 | | 72 | 232 |
| 41 | do. | 41 | 729 | 72.2 | Turned left off U.S. 17 | | |
| 41.9 | Myakka City; Junction Fla. 18a & Fla. 63; turned north toward Wauchula | | | 72.3 | R.R. crossing | | |
| | | | | 72.6 | Worn-out pavement leading to Fla. 32 begins | | |
| | | | | | | | |
| 42 | Fla. 63 | 42 | 740 | 73 | Fla. 32 | 73 | 228 |
| 43 | do. | 43 | 760 | 74 | do. | 74 | 217 |
| 44 | do. | 44 | 788 | 75 | do. | 75 | 220 |
| 45 | do. | 45 | 820 | 76 | do. | 76 | 220 |
| 46 | do. | 46 | 839 | 77 | do. | 77 | 240 |
| | | | | | | | |
| 47 | do. | 47 | 873 | 77.6 | Junction Fla. 32 | | |
| 48 | do. | 48 | 896 | 78 | Fla. 32 | 78 | 45266 |
| 49 | do. | 49 | 915 | 79 | do. | 79 | 275 |
| 49.5 | Road turns to east | | | 80 | do. | 80 | 250 |
| 50 | Fla. 63 | 50 | 946 | 81 | do. | 81 | 259 |
| | | | | | | | |
| 51 | do. | 51 | 981 | 82 | do. | 82 | 45257 |
| 52 | do. | 52 | 45016 | 83 | do. | 83 | 256 |
| 53 | do. | 53 | 072 | 83.8 | Big Charlie Creek | | |
| 54 | do. | 54 | 110 | 84 | Fla. 32 | 84 | 261 |
| 55 | do. | 55 | 152 | 85 | do. | 85 | 286 |

Florida magnetic traverse F (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------------------------|----------------|-----------------------------|-------|---|----------------|-----------------------------|
| 86 | Fla. 32 | 86 | 289 | 112 | | 112 | 066 |
| 87 | do. | 87 | 297 | 112.9 | Small creek | | |
| 88 | do. | 88 | 296 | 113 | | 113 | 040 |
| 89 | do. | 89 | 263 | 114 | | 114 | 44998 |
| 90 | do. | 90 | 245 | 115 | | 115 | 45005 |
| 91 | do. | 91 | 231 | 116 | | 116 | 015 |
| 92 | do. | 92 | 201 | 117 | | 117 | 020 |
| 92.1 | Junction Fla. 8 & Fla. 32 | | | 118 | | 118 | 029 |
| 92.6 | R.R. crossing; also at | 92.7 | | 118.3 | Junction with Fla. 59 | | |
| 93 | Avon Park; Fla. 8 | 93 | 179 | 119 | Fla. 59 | 119 | 037 |
| 94 | | | 176 | 120 | do. | 120 | 046 |
| 95 | Fla. 8 turns south | | | 121 | do. | 121 | 027 |
| 95 | | 95 | 145 | 122 | do. | 122 | 44999 |
| 96 | Fla. 8 | 96 | 115 | 123 | do. | 123 | 952 |
| 97 | do. | 97 | 098 | 123.8 | Creek | | |
| 98 | do. | 98 | 062 | 124 | Fla. 59 | 124 | 911 |
| 98.8 | R.R. crossing | | | 124.1 | Kissimmee River Canal | | |
| 99 | Fla. 8 | 99 | 012 | 124.5 | Turn N.E. along R.R. | | |
| 101 | do. | 100 | 44977 | 125 | Fla. 59 | 125 | 855 |
| 101 | do. | 101 | 929 | 126 | do. | 126 | 837 |
| 102 | Turned east | 102 | 864 | 127 | do. | 127 | 846 |
| 102.3 | R.R. crossing | | | 127 | Road swung away from R.R. tracks | | |
| 102.4 | Turned north | | | 128 | Fla. 59 | 128 | 881 |
| 103 | Fla. 8 | 103 | 933 | 129 | do. | 129 | 893 |
| 103.5 | Turned east onto Bassenger road | | | 130 | do. | 130 | 904 |
| 104 | | 104 | 948 | 131 | do. | 131 | 907 |
| 105 | | 105 | 950 | 131.6 | do. | 131a | 940 |
| 106 | | 106 | 963 | 131.6 | Turned left onto Long Bridge across Kissimmee River | | |
| 106.6 | Small creek | | | 133 | Fla. 59 | 132 | 45062 |
| 107 | | 107 | 960 | 134 | do. | 133 | 45156 |
| 108 | | 108 | 44954 | 135 | | 134 | 260 |
| 108.5 | Large creek | | | 136 | | 135 | 343 |
| 109 | | 109 | 982 | 137 | | 136 | 433 |
| 110 | | 110 | 45044 | 137.3 | Took left fork of road | | |
| 111 | | 111 | 078 | | | | |

Florida magnetic traverse F (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|------------------------------------|----------------|-----------------------------|
| 138 | | 137 | 551 | 146 | | 145 | 795 |
| 138 | Stations 137, 138, 139 stake station markers put in | | | 147 | | 146 | 804 |
| 139 | | 138 | 670 | 148 | | 147 | 766 |
| 140 | | 139 | 713 | 148.4 | Junction Fla. 29 | | |
| 141 | | 140 | 708 | 157.7 | Junction Fla. 8 & 29 in Okeechobee | | |
| 142 | | 141 | 703 | | | | |
| 143 | | 142 | 701 | | | | |
| 144 | | 143 | 723 | | | | |
| 145 | | 144 | 772 | | | | |

Florida magnetic traverse G

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|--------------------|----------------|-----------------------------|
| 0 | On beach at Rio Mar | | | 13 | Fla. 30 | 14 | 367 |
| 0 | | 1 | 45523 | 14 | do. | 15 | 351 |
| 1 | | 2 | 526 | 15 | do. | 16 | 372 |
| 1 | East of Vero Beach | | | 16 | do. | 17 | 388 |
| 1.8 | Mainland | | | 17 | do. | 18 | 380 |
| 2 | | 3 | 511 | 18 | do. | 19 | 352 |
| 3 | | 4 | 453 | 19 | do. | 20 | 325 |
| 3 | Inside city limits of Vero Beach | | | 20 | do. | 21 | 352 |
| 3.1 | R.R. crossing | | | 21 | do. | 22 | 362 |
| 4 | | 5 | 470 | 22 | do. | 23 | 366 |
| 4 | Fla. 30, west edge of Vero Beach | | | 23 | do. | 24 | 371 |
| 5 | Fla. 30 | 6 | 451 | 24 | do. | 25 | 360 |
| 6 | do. | 7 | 446 | 25 | do. | 26 | 335 |
| 7 | do. | 8 | 440 | 26 | do. | 27 | 331 |
| 8 | do. | 9 | 430 | 26 | Road curves to NW. | | |
| 9 | do. | 10 | 446 | 27 | Fla. 30 | 28 | 45331 |
| 10 | do. | 11 | 448 | 28 | do. | 29 | 331 |
| 11 | do. | 12 | 438 | 29 | do. | 30 | 377 |
| 12 | do. | 13 | 399 | 30 | do. | 31 | 412 |
| 12 | Edge of fill; drainage ditch both sides of road | | | 31 | do. | 32 | 500 |

Florida magnetic traverse G (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-----------------------------------|----------------|-----------------------------|-------|-----------------------------------|----------------|-----------------------------|
| 32 | Fla. 30 | 33 | 618 | 63.6 | Filled ground; Fla. 30 & 79 | | |
| 33 | do. | 34 | 758 | 64 | Fla. 30 | 64 | 061 |
| 33.2 | R.R. crossing | | | 65 | do. | 65 | 073 |
| 34 | | 35 | 867 | 66 | do. | 66 | 076 |
| 34 | Stations 35 & 36 marked by stakes | | | 67 | do. | 67 | 119 |
| 35 | Fla. 30 | 36 | 890 | 68 | do. | 68 | 147 |
| 36 | do. | 37 | 882 | 69 | do. | 69 | 180 |
| 36.3 | Junction Fla. 30 | 29 | | 70 | do. | 70 | 199 |
| 37 | Fla. 30 | 38 | 855 | 71 | do. | 71 | 231 |
| 38 | do. | 39 | 833 | 72 | do. | 72 | 228 |
| 39 | do. | 40 | 788 | 72.5 | Low hills running north and south | | |
| 40 | do. | 41 | 768 | 73 | | 73 | 269 |
| 41 | do. | 42 | 754 | 74 | Fla. 30 | 74 | 278 |
| 42 | do. | 43 | 753 | 75 | do. | 75 | 291 |
| 43 | do. | 44 | 767 | 75.2 | Turn right; junction | | |
| 44 | do. | 45 | 808 | 76 | Circling lake | 76 | 315 |
| 45 | do. | 46 | 844 | 77 | | 77 | 338 |
| 46 | do. | 47 | 881 | 78 | | 78 | 353 |
| 47 | do. | 48 | 904 | 78.7 | Turned left | | |
| 48 | do. | 49 | 900 | 79 | | 79 | 390 |
| 49 | do. | 50 | 849 | 79.5 | Turned right, R.R. crossing | | |
| 50 | do. | 51 | 737 | 79.7 | Frostproof | | |
| 51 | do. | 52 | 719 | 79.9 | Turned left | | |
| 52 | do. | 53 | 528 | 80 | | 80 | 414 |
| 53 | do. | 54 | 476 | 81 | Fla. 30 | 81 | 443 |
| 54 | do. | 55 | 379 | 82 | do. | 82 | 482 |
| 55 | do. | 56 | 263 | 83 | do. | 83 | 505 |
| 56 | Middle Kissimmee River | | | 84 | R.R. crossing | | |
| 56.6 | Fla. 30 | 57 | 189 | 84.1 | Fla. 30 | 84 | 572 |
| 58 | do. | 58 | 122 | 85 | do. | 85 | 621 |
| 59 | do. | 59 | 45058 | 86 | do. | 86 | 45684 |
| 60 | do. | 60 | 028 | 87 | do. | 87 | 766 |
| 61 | do. | 61 | 022 | 88 | do. | 88 | 828 |
| 62 | do. | 62 | 030 | 89 | do. | 89 | 831 |
| 63 | do. | 63 | 056 | 90 | do. | 90 | 799 |

Florida magnetic traverse G (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|----------------------------------|----------------|-----------------------------|
| 91 | Fla. 30 | 91 | 774 | 114 | On concrete road, heavily fenced | | |
| 92 | do. | 92 | 780 | 115 | | 115 | 633 |
| 93 | do. | 93 | 795 | 116 | | 116 | 621 |
| 93.1 | Road turns north for about 1 mile and then turns west again | | | 117 | | 117 | 632 |
| | | | | 117 | Turned west on old road | | |
| 94 | Fla. 30 | 94 | 348 | 118 | | 118 | 644 |
| 95 | do. | 95 | 860 | 119 | | 119 | 669 |
| 95.4 | R.R. crossing | | | 120 | | 120 | 697 |
| 96 | Fla. 30 | 96 | 844 | 121 | | 121 | 723 |
| 97 | do. | 97 | 785 | 122 | | 122 | 747 |
| 98 | do. | 98 | 824 | 123 | | 123 | 776 |
| 98 | East Edge Fort Meade, Fla. | | | 124 | | 124 | 805 |
| 99 | Fla. 30 | 99 | 794 | 124.8 | Cross road; Fort Lonesome | | |
| 99 | Junction with U.S. 17 | | | 125 | | 125 | 827 |
| 99.3 | R.R. crossing Fort Meade | | | 126 | | 126 | 855 |
| 100 | West edge Fort Meade | | | 127 | | 127 | 839 |
| 100 | | 100 | 792 | 128 | In slough | 128 | 822 |
| 101 | | 101 | 760 | 129 | | 129 | 746 |
| 102 | | 102 | 776 | 130 | Filled ground | 130 | 675 |
| 102.6 | R.R. crossing | | | 131 | | 131 | 598 |
| 103 | | 103 | 755 | 132 | | 132 | 523 |
| 104 | | 104 | 730 | 132.9 | Road junction | | |
| 104.6 | Turned south; road junction | | | 133 | | 133 | 476 |
| 105 | | 105 | 718 | 134 | | 134 | 392 |
| 105.6 | Turned west again | | | 134.4 | R.R. crossing | | |
| 106 | | 106 | 680 | 134.6 | Wimauma, Fla. | | |
| 107 | | 107 | 702 | 135 | | 135 | 357 |
| 108 | | 108 | 704 | 136 | | 136 | 352 |
| 109 | | 109 | 708 | 136.7 | Junction U.S. 41 | | |
| 109.9 | R.R. crossing | | | 137 | | 137 | 387 |
| 110 | | 110 | 45689 | 138 | | 138 | 405 |
| 110.6 | Center phosphate mine | | | 139 | | 139 | 431 |
| 111 | | 111 | 693 | 140 | | 140 | 451 |
| 111.7 | R.R.; east edge Brewster | | | 141 | | 141 | 456 |
| 112 | | 112 | 673 | 142 | | 142 | 480 |
| 112.2 | Brewster, Fla. | | | 142.4 | R.R. crossing | | |
| 112.7 | Turned south | | | 142.8 | Ruskin | | |
| 113 | | 113 | 671 | 142.9 | U.S. 54 | | |
| 114 | | 114 | 657 | 143 | | 143 | 482 |
| | | | | 143.7 | Turned south | | |
| | | | | 144 | | 144 | 497 |
| | | | | 144.3 | Swung back to U.S. 541 | | |

Florida magnetic traverse H

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|-------|---|----------------|-----------------------------|
| 0 | Started line H on Fla. Highway 228; Ozone, Fla., beach | | | 26 | U.S. 92 | 26 | 45876 |
| 0 | Fla. 228 | 1 | 45640 | 26.3 | Fla. 156 crosses U.S. 92 | | |
| 0.5 | R.R. crossing | | | 27 | U.S. 92 | 27 | 851 |
| 1 | Junction U.S. 19 | 2 | 636 | 28 | do. | 28 | 819 |
| | | | | 29 | do. | 29 | 807 |
| 2 | | 3 | 630 | 30 | do. | 30 | 796 |
| 2.9 | Crossroad | | | 31 | do. | 31 | 802 |
| 3 | | 4 | 604 | 32 | do. | 32 | 830 |
| 4 | | 5 | 597 | 33 | do. | 33 | 821 |
| 5 | | 6 | 575 | 34 | do. | 34 | 838 |
| 6 | | 7 | 577 | 35 | do. | 35 | 838 |
| 7 | Junction Fla. 17 | 8 | 593 | 36 | do. | 36 | 844 |
| 8 | Fla. 17 | 9 | 623 | 37 | do. | 37 | 868 |
| 8.1 | R.R. crossing | | | 38 | do. | 38 | 881 |
| 9 | Fla. 17 | 10 | 675 | 39 | do. | 39 | 893 |
| 10 | do. | 11 | 747 | 40 | do. | 40 | 884 |
| 11 | do. | 12 | 793 | 41 | do. | 41 | 854 |
| 12 | do. | 13 | 844 | 41.9 | City limit, Plant City | | |
| 13 | do. | 14 | 893 | 42 | | 42 | 786 |
| 14 | do. | 15 | 933 | 42.8 | Junction Fla. 23 | | |
| 14.1 | Turned left on Fla. 17 | | | 43 | R.R. crossing | | |
| 15 | Fla. 17 | 16 | 982 | 44 | | 43 | 736 |
| 16 | do. | 17 | 46018 | 45.2 | | 44 | 746 |
| 17 | do. | 18 | 055 | 46 | | 45 | 762 |
| 18 | do. | 19 | 061 | 47 | U.S. 92 | 46 | 740 |
| 19 | do. | 20 | 053 | 48 | do. | 47 | 737 |
| 20 | do. | 21 | 048 | 49 | do. | 48 | 720 |
| 20.1 | Cross road | | | 50 | do. | 49 | 712 |
| 21 | | 22 | 026 | 51 | do. | 50 | 699 |
| 21.7 | Intersection U.S. 541, 41, and 92, Tampa, going east on U.S. 92, Tampa | | | 52 | do. | 51 | 701 |
| 23 | | 23 | 003 | 52.7 | R.R. underpass & city limit of Lakeland | | |
| 23.5 | R.R. crossing | | | 53 | | 52 | 663 |
| 24 | E. edge Tampa | 24 | 45924 | 54 | Center Lakeland | | |
| 25 | U.S. 92 | 25 | 905 | 54.4 | R.R. crossing | | |
| 25.5 | R.R. crossing | | | 55 | U.S. 92 | 53 | 669 |
| | | | | 55.1 | R.R. underpass | | |

Florida magnetic traverse H (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------------------|----------------|-----------------------------|-------|------------------------------|----------------|-----------------------------|
| 56 | U.S. 92 | 54 | 45652 | 93 | U.S. 92 | 89 | 811 |
| 57 | do. | 55 | 585 | 93.1 | Detour begins; turns north | | |
| 58 | do. | 56 | 550 | 93.5 | Turned east | | |
| 59.5 | | 57 | 529 | 94 | | 90 | 808 |
| 61 | | 58 | 546 | 95 | Swamp. R.R. to north | | |
| 62 | | 59 | 542 | 95.5 | | 91 | 834 |
| 63 | | 60 | 567 | 96 | Jogged to north side of R.R. | | |
| 64 | | 61 | 583 | 97 | | 92 | 879 |
| 64.3 | R.R. overpass; Auburndale | | | 97.6 | Kissimmee city limits | | |
| 65 | | 62 | 599 | 98 | | 93 | 886 |
| 66 | | 63 | 615 | 98.1 | Detour ends | | |
| 67 | | 64 | 629 | 98.6 | Kissimmee | | |
| 68 | | 65 | 637 | 99 | U.S. 92 | 94 | 868 |
| 68.5 | Junction with U.S. 17 | | | 99.4 | Junction U.S. 92 & U.S. 192 | | |
| 68.7 | R.R. crossing | | | 99.7 | R.R. crossing | 94 | 868 |
| 69 | | 66 | 656 | 100 | U.S. 92 | 95 | 962 |
| 70 | Lake Alfred | 67 | 650 | 101 | do. | 96 | 994 |
| 71 | U.S. 92 | 68 | 676 | 102 | do. | 97 | 976 |
| 72 | do. | 69 | 702 | 103 | do. | 98 | 949 |
| 73 | do. | 70 | 712 | 103.8 | Cross road | | |
| 74 | do. | 71 | 711 | 104 | U.S. 192 | 99 | 926 |
| 75 | do. | 72 | 675 | 105 | do. | 100 | 903 |
| 76 | do. | 73 | 677 | 106 | do. | 101 | 940 |
| 76 | Edge of Haines City | | | 106.8 | R.R. crossing; side road | | |
| 77 | Water tower, Haines City | | | 107 | U.S. 192 | 102 | 998 |
| 77.5 | U.S. 92 | 74 | 706 | 108 | do. | 103 | 46036 |
| 79 | do. | 75 | 711 | 108.5 | St. Cloud | | |
| 80 | do. | 76 | 722 | 109 | U.S. 192 | 104 | 083 |
| 81 | do. | 77 | 720 | 110 | do. | 105 | 096 |
| 82 | do. | 78 | 757 | 110.9 | Junction Fla. 29 | | |
| 83 | do. | 79 | 775 | 111 | U.S. 192 | 106 | 45122 |
| 84 | do. | 80 | 779 | 112 | do. | 107 | 120 |
| 85 | do. | 81 | 783 | 113 | do. | 108 | 119 |
| 86 | do. | 82 | 816 | 114 | do. | 109 | 109 |
| 87 | do. | 83 | 810 | 115 | do. | 110 | 062 |
| 88 | do. | 84 | 45833 | 116 | do. | 111 | 017 |
| 89 | do. | 85 | 850 | 117 | do. | 112 | 985 |
| 90 | do. | 86 | 850 | 118 | do. | 113 | 971 |
| 91 | do. | 87 | 847 | 119 | do. | 114 | 953 |
| 92 | do. | 88 | 820 | 120 | do. | 115 | 928 |

Florida magnetic traverse H (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------------------------|----------------|-----------------------------|----------------|--|----------------|-----------------------------|
| 121 | U.S. 192 | 116 | 906 | 140 | U.S. 192 | 135 | 650 |
| 122 | do. | 117 | 883 | 141 | do. | 136 | 653 |
| 123 | do. | 118 | 872 | 142 | do. | 137 | 637 |
| 124 | do. | 119 | 876 | 143 | do. | 138 | 643 |
| 124.4 | Junction Fla. 29; R.R. crossing | | | 144 | do. | 139 | 643 |
| 125 | U.S. 192 | 120 | 884 | 144.2 to 146.3 | Swamp, metal guard rail both sides of road | | |
| 126 | do. | 121 | 879 | 145.5 | St. Johns River | | |
| 127 | do. | 122 | 915 | 146.5 | U.S. 192 | 140 | 45625 |
| 128 | do. | 123 | 916 | 148 | do. | 141 | 600 |
| 129 | do. | 124 | 893 | 149 | do. | 142 | 579 |
| 130 | do. | 125 | 862 | 150 | do. | 143 | 548 |
| 131 | do. | 126 | 834 | 151 | do. | 144 | 535 |
| 132 | do. | 127 | 815 | 152 | do. | 145 | 524 |
| 133 | do. | 128 | 805 | 153 | do. | 146 | 525 |
| 134 | do. | 129 | 777 | 154 | do. | 147 | 512 |
| 135 | do. | 130 | 754 | 154.8 | R.R. crossing; Melbourne, Fla. | | |
| 136 | do. | 131 | 715 | 154.9 | Junction U.S. 1 | | |
| 137 | do. | 132 | 661 | 155 | Shore line | 148 | 494 |
| 138 | do. | 133 | 660 | 157.5 | | 149 | 552 |
| 139 | do. | 134 | 661 | 157.5 | Beach Indian Atlantic; end of line H | | |

Florida magnetic traverse I

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-----------|--|----------------|-----------------------------|
| 0 | At a point approximately 200 ft. east U.S. C & G.S. triangulation station at Titusville Beach | | | 8 | Fla. 119 | 9 | 057 |
| 0 | Fla. 119 | 1 | 46088 | 9 | do. | 10 | 058 |
| 1 | do. | 2 | 080 | 9.2 | Side road north | | |
| 1.6 | Sand road south | | | 10 | Fla. 119 | 11 | 050 |
| 2 | Fla. 119 | 3 | 095 | 10.8 | do. | 12 | 027 |
| 3 | do. | 4 | 085 | 10.9-12.4 | Bridge | | |
| 4 | do. | 5 | 071 | 12.4 | | 13 | 013 |
| 5 | do. | 6 | 054 | 12.4 | Bridge ends; junction Fla. 119 & U.S. 1; road jogs south 0.2 mile then west, on Fla. 119 | | |
| 6 | do. | 7 | 047 | | | | |
| 6.1 | Pavement begins | | | | | | |
| 7 | Fla. 119 | 8 | 040 | | | | |

Florida magnetic traverse I (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|------------------------|----------------|-----------------------------|--------------|-------------------------|----------------|-----------------------------|
| 12.8 | R.R. crossing | | | 41 | Fla. 22 | 41 | 008 |
| 13 | Titusville | | | 42 | do. | 42 | 45988 |
| 13.1 | R.R. crossing | | | 43 | do. | 43 | 46013 |
| 14 | Fla. 119 | 14 | 013 | 44 | do. | 44 | 023 |
| 15 | do. | 15 | 45980 | 44.3 | Cross road | | |
| 16 | do. | 16 | 953 | 45 | Fla. 22 | 45 | 018 |
| 17 | do. | 17 | 950 | 46 | do. | 46 | 044 |
| 18 | do. | 18 | 921 | 46.8 | Cross road | | |
| 18.5 | Junction Fla. 119 & 22 | | | 47 | | 47 | 044 |
| 19 | Fla. 22 | 19 | 902 | 48 | | 48 | 042 |
| 20 | do. | 20 | 929 | 49 | | 49 | 035 |
| 21 | do. | 21 | 974 | 50 | | 50 | 030 |
| 22 | do. | 22 | 46011 | 50.2 | Cross road | | |
| 23 | do. | 23 | 094 | 51 | | 51 | 065 |
| 24 | do. | 24 | 190 | 51.5 | Orlando City limit | | |
| 24.8 | St. Johns River | | | 52 | | 52 | 46082 |
| 25 | Fla. 22 | 25 | 46275 | 53 | Junction U.S. 17 & 92 | | |
| 26 | do. | 26 | 308 | 53.6 | Turned right on Fla. 22 | | |
| 27 | do. | 27 | 307 | 53.7 | R.R. crossing | | |
| 28 | do. | 28 | 309 | 54.7 | Junction U.S. 92 bypass | | |
| 29 | do. | 29 | 316 | 52.0 to 55.0 | Orlando | | |
| 29.1 | Fla. 296 south | | | 55 | Fla. 22 | 53 | 46081 |
| 29.4 | do. | | | 56 | do. | 54 | 319 |
| 29.4 | Christmas | | | 57 | do. | 55 | 424 |
| 30 | Fla. 22 | 30 | 319 | 58 | do. | 56 | 410 |
| 31 | do. | 31 | 317 | 59 | | 57 | 334 |
| 32 | do. | 32 | 285 | 59.8 | Cross road | | |
| 33 | do. | 33 | 267 | 60 | | 58 | 352 |
| 34 | do. | 34 | 247 | 61 | | 59 | 179 |
| 35 | do. | 35 | 208 | 61 | Side road south | | |
| 35.4 | Bithlo | | | 62 | | 60 | 156 |
| 35.5 | R.R. crossing | | | 63 | | 61 | 221 |
| 36 | Fla. 22 | 36 | 272 | 63.9 | Side road south | | |
| 36.9 | Junction Fla. 203 | | | 64 | | 62 | 328 |
| 37 | Fla. 22 | 37 | 124 | 65 | Ocoee | 63 | 401 |
| 38 | do. | 38 | 087 | | | | |
| 39 | do. | 39 | 068 | | | | |
| 40 | do. | 40 | 029 | | | | |

Florida magnetic traverse I (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|------------------------------------|----------------|-----------------------------|
| 65.4 | R.R. crossing | | | 83.2 | Crossed R.R. and back on main road | | |
| 66 | | 64 | 494 | 84 | | 84 | 221 |
| 67 | | 65 | 517 | 85 | | 85 | 245 |
| 68 | | 66 | 460 | 86 | | 86 | 289 |
| 68 | Church yard, Winter Garden, Fla. | | | 87 | | 87 | 322 |
| 68.3 | R.R. crossing | | | 87.6 | Jct. Fla. 2 | | |
| 69 | | 67 | 46493 | 88 | Groveland | 88 | 302 |
| 69.8 | Junction Fla. | 208 | | 89 | Fla. 22 | 89 | 244 |
| 70 | | 68 | 448 | 90 | do. | 90 | 243 |
| 70.9 | R.R. crossing | | | 90 | Fla. 2 turns north | | |
| 71 | Oakland | 69 | 477 | 90.4 | Mascotte | | |
| 72 | | 70 | 394 | 90.6 | R.R. crossing | | |
| 72.7 | R.R. crossing | | | 91 | Fla. 22 | 91 | 46213 |
| 73 | | 71 | 400 | 92 | do. | 92 | 199 |
| 74 | | 72 | 384 | 93 | do. | 93 | 202 |
| 75 | | 73 | 46388 | 94 | do. | 94 | 237 |
| 75.1 | Side road south | | | 94.8 | Junction Fla. | 51 | |
| 75.4 | Side road north | | | 95 | Fla. 51 | 95 | 303 |
| 76 | | 74 | 357 | 95.9 | R.R.; Mabel | | |
| 77 | | 75 | 335 | 96 | Fla. 51 | 96 | 320 |
| 78 | | 76 | 310 | 96.6 | R.R. crossing | | |
| 79 | | 77 | 305 | 97 | Fla. 51 | 97 | 298 |
| 79.1 | R.R. crossing | | | 98 | do. | 98 | 296 |
| 79.8 | Junction Fla. | 55 | | 99 | do. | 99 | 306 |
| 80 | Minneola | 78 | 324 | 100 | do. | 100 | 283 |
| 80.9 | Side road to SW. | | | 100 | Crossed to north side R.R.; Linden | | |
| 81 | | 79 | 307 | 101 | | 101 | 336 |
| 81.6 | R.R. crossing | | | 101.4 | Road junction | | |
| 82 | Clermont | 80 | 287 | 102 | | 102 | 395 |
| | Main road Clermont to Groveland closed. Returned to 79.8 miles and followed detour around north side of lake. | | | 103 | | 103 | 458 |
| | | | | 104 | | 104 | 489 |
| | | | | 105 | | 105 | 420 |
| | | | | 105.2 | R.R. crossing | | |
| | | | | 106 | | 106 | 245 |
| 79.8 | Beginning of detour | | | 107 | | 107 | 091 |
| 80 | Detour | 80a | 366 | 108 | | 108 | 018 |
| 81 | do. | 81a | 366 | 108.2 | Road junction; Richloam | | |
| 82 | do. | 82a | 298 | 109 | | 109 | 45991 |
| 83 | do. | 83 | 237 | 110 | | 110 | 951 |

Florida magnetic traverse I (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------------------------|----------------|-----------------------------|-------|--|----------------|-----------------------------|
| 110.9 | Junction Fla. 23 South | | | 128 | Brooksville | | |
| 111 | | 111 | 894 | 128.3 | R.R. crossing | | |
| 111.2 | R.R. crossing | | | 129 | U.S. 19 | 129 | 280 |
| 111.8 | Junction Fla. 23 (main highway) | | | 130 | do. | 130 | 298 |
| 112 | Fla. 51 | 112 | 45896 | 131 | do. | 131 | 292 |
| 113 | do. | 113 | 45889 | 132 | do. | 132 | 288 |
| 114 | do. | 114 | 892 | 133 | do. | 133 | 267 |
| 114.8 | Big Creek | | | 134 | do. | 134 | 255 |
| 115 | | 115 | 921 | 135 | do. | 135 | 267 |
| 115.3 | R.R. & cross road | | | 136 | do. | 136 | 277 |
| 116 | Fla. 51 | 116 | 936 | 137 | do. | 137 | 289 |
| 117 | do. | 117 | 915 | 138 | do. | 138 | 304 |
| 118 | do. | 118 | 936 | 139 | do. | 139 | 311 |
| 119 | do. | 119 | 934 | 140 | do. | 140 | 320 |
| 120 | do. | 120 | 928 | 140.8 | Road junction, Fla. 15 turned northward to Bayport | | |
| 120.8 | Junction Fla. 51 & 34 | | | 141 | | 141 | 46318 |
| 121 | | 121 | 936 | 142 | | 142 | 311 |
| 122 | | 122 | 970 | 143 | | 143 | 312 |
| 123 | | 123 | 46020 | 144 | | 144 | 332 |
| 124 | | 124 | 075 | 145 | | 145 | 328 |
| 125 | | 125 | 116 | 146 | | 146 | 327 |
| 125.9 | R.R. crossing | | | 146.3 | Junction to Pine Island | | |
| 126 | | 126 | 145 | 147 | | 147 | 305 |
| 127 | | 127 | 193 | 147 | Bayport, Fla.; end line I | | |
| 128 | | 128 | 226 | | | | |

Florida magnetic traverse J

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-------------------|----------------|-----------------------------|-------|-------------------------|----------------|-----------------------------|
| 0 | Homosassa Beach | | | 6 | Fla. 268 | 7 | 379 |
| 0 | | 1 | 46361 | 7 | do. | 8 | 357 |
| 0.6 | R.R. crossing | | | 8 | do. | 9 | 362 |
| 1 | | 2 | 359 | 8.7 | Tampa high-tension line | | |
| 2 | | 3 | 380 | 9 | Fla. 268 | 10 | 375 |
| 3 | | 4 | 375 | 10 | do. | 11 | 394 |
| 3.7 | Junction Fla. 15 | | | 10.6 | Junction Fla. 22 | | |
| 4 | | 5 | 365 | 11 | Fla. 22 | 12 | 392 |
| 4.2 | Homosassa Springs | | | 11.1 | Lecanto, cross road | | |
| 5 | Fla. 268 | 6 | 377 | 12 | Fla. 22 | 13 | 428 |

Florida magnetic traverse J (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-------------------------------------|----------------|-----------------------------|-------|----------------------------------|----------------|-----------------------------|
| 13 | Fla. 22 | 14 | 453 | 41 | Fla. 36 | 42 | 503 |
| 14 | do. | 15 | 486 | 41.4 | R.R. crossing | | |
| 15 | do. | 16 | 505 | 41.5 | Junction Fla. 23; Wildwood, Fla. | | |
| 16 | do. | 17 | 483 | 42 | Fla. 36 | 43 | 480 |
| 17 | do. | 18 | 472 | 43 | do. | 44 | 450 |
| 18 | Fla. 22 | 19 | 46492 | 44 | do. | 45 | 380 |
| 19 | do. | | 511 | 45 | R.R. crossing | 46 | 382 |
| 19.5 | R.R. crossing | | | 46 | Fla. 36 | 47 | 378 |
| 20 | Fla. 22 | 21 | 518 | 46.7 | Side road south | | |
| 21 | | 22 | 525 | 47 | Fla. 36 | 48 | 522 |
| 21 | Junction Fla. 22 & U.S. 19 & 41 | | | 48 | do. | 49 | 567 |
| 21.5 | Inverness | | | 49 | do. | 50 | 581 |
| 22 | | 23 | 600 | 50 | do. | 51 | 539 |
| 22.3 | Turned left off U.S. 41 via Fla. 36 | | | 51 | do. | 52 | 529 |
| 23 | Fla. 36 | 24 | 574 | 52 | do. | 53 | 505 |
| 24 | Rocky dirt road | 25 | 595 | 52.5 | R.R. crossing; junction U.S. 441 | | |
| 25 | Fla. 36 | 26 | 608 | 52.7 | Leesburg, Fla. | | |
| 26 | do. | 27 | 622 | 53.7 | R.R. crossing | | |
| 27 | do. | 28 | 635 | 54 | U.S. 441 | 54 | 382 |
| 28 | do. | 29 | 622 | 55 | do. | 55 | 383 |
| 28.7 | Pavement begins | | | 56 | do. | 56 | 448 |
| 29 | Fla. 36 | 30 | 615 | 57 | do. | 57 | 525 |
| 29.4 | Bridge; Withlacoochee River | | | 57 | Junction Fla. 2, U.S. 441 | | |
| 30 | Rutland | 31 | 613 | 58 | U.S. 441 | 58 | 531 |
| 31 | Fla. 36 | 32 | 613 | 59 | do. | 59 | 559 |
| 32 | do. | 33 | 585 | 60 | do. | 60 | 647 |
| 33 | do. | 34 | 575 | 61 | do. | 61 | 709 |
| 34 | do. | 35 | 560 | 61.2 | Dead River | | |
| 35 | do. | 36 | 548 | 62 | U.S. 441 | 62 | 782 |
| 36 | do. | 37 | 548 | 63 | do. | 63 | 846 |
| 37 | do. | 38 | 46533 | 63.2 | Junction Fla. 55 | | |
| 38 | do. | 39 | 500 | 63.5 | Tavares | | |
| 39 | do. | 40 | 501 | 63.8 | R.R. crossing | | |
| 40 | do. | 41 | 560 | 64 | Junction Fla. 55 | 64 | 46905 |
| 40 | Swamp; filled ground on highway | | | 65 | U.S. 441 | 65 | 955 |

Florida magnetic traverse J (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|------------------------------------|----------------|-----------------------------|-------|-----------------------|----------------|-----------------------------|
| 66 | | 66 | 954 | 94 | Fla. 57 | 94 | 841 |
| 66.8 | Road junction | | | 94 | Turned left | | |
| 67 | | 67 | 943 | 95 | Fla. 57 | 95 | 942 |
| 68 | | 68 | 947 | 95.5 | Edge of city | | |
| 68.7 | Mt. Dora, Fla. | | | 96 | Fla. 57 | 96 | 47011 |
| 69.2 | | 69 | 911 | 96.3 | St. Johns River | | |
| 69.6 | Turned left, Fla. 44 | 44 | | 97 | Fla. 57 | 97 | 46949 |
| 70 | Fla. 44 | 70 | 934 | 98 | do. | 98 | 945 |
| 71 | do. | 71 | 978 | 99 | do. | 99 | 47012 |
| 72 | do. | 72 | 981 | 100 | do. | 100 | 078 |
| 73 | do. | 73 | 958 | 101 | | 101 | 096 |
| 74 | do. | 74 | 900 | 101 | R.R. crossing; Osteen | | |
| 74.3 | R.R. crossing | | | 102 | Fla. 57 | 102 | 121 |
| 74.4 | Sorrento | | | 103 | do. | 103 | 173 |
| 75 | Fla. 44 | 75 | 862 | 104 | do. | 104 | 165 |
| 76 | do. | 76 | 810 | 105 | do. | 105 | 135 |
| 77 | do. | 77 | 819 | 106 | do. | 106 | 014 |
| 78 | do. | 78 | 812 | 107 | do. | 107 | 46980 |
| 79 | do. | 79 | 766 | 108 | do. | 108 | 47000 |
| 80 | do. | 80 | 774 | 109 | do. | 109 | 031 |
| 80.3 | R.R. crossing | | | 110 | do. | 110 | 056 |
| 80.7 | Fla. 44 | 81 | 811 | 111 | do. | 111 | 086 |
| 82 | do. | 82 | 873 | 112 | do. | 112 | 100 |
| 83 | do. | 83 | 959 | 113 | do. | 113 | 097 |
| 83.5 | River | | | 114 | do. | 114 | 061 |
| 84 | Fla. 44 | 84 | 47005 | 115 | do. | 115 | 47040 |
| 85 | do. | 85 | 020 | 116 | do. | 116 | 040 |
| 86 | do. | 86 | 46954 | 116.5 | Samsula | | |
| 87 | do. | 87 | 861 | 117 | Fla. 57 | 117 | 068 |
| 87.1 | Cross road | | | 118 | do. | 118 | 107 |
| 88 | Fla. 44 | 88 | 46816 | 118.5 | Junction Fla. 75 | | |
| 89 | do. | 89 | 909 | 119 | Fla. 75 | 119 | 120 |
| 89.7 | Cross road | | | 120 | do. | 120 | 069 |
| 90 | Fla. 44 | 90 | 864 | 121 | do. | 121 | 053 |
| 91 | do. | 91 | 842 | 122 | do. | 122 | 032 |
| 92 | do. | 92 | 791 | 123 | do. | 123 | 46984 |
| 93 | do. | 93 | 715 | 124 | do. | 124 | 940 |
| 93 | R.R. freight depot | | | 124.5 | Blencoe | | |
| 93.1 | Junction U.S. 17, U.S. 92, Sanford | | | 125 | Fla. 75 | 125 | 958 |
| 93.3 | Turned right on Fla. 57 | | | 126 | do. | 126 | 982 |

Florida magnetic traverse J (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|-------|-------------------------------|----------------|-----------------------------|
| 127 | Fla. 75 | 127 | 968 | 139 | U.S. 1 | 139 | 716 |
| 127.5 | R.R. crossing | | | 140 | Oakhill | 140 | 604 |
| 127.6 | Junction Fla. 75 & U.S. 1 & New Smyrna Beach | | | 141 | U.S. 1 | 141 | 499 |
| 128 | U.S. 1 | 128 | 022 | 142.1 | Turned off U.S. 1 | | |
| | | | | 142.2 | U.S. 1 | 142 | 427 |
| 129 | do. | 129 | 151 | 143 | | 143 | 46371 |
| 130.2 | do. | 130 | 202 | 144 | | 144 | 329 |
| 131 | do. | 131 | 281 | 145 | | 145 | 279 |
| 132 | do. | 132 | 243 | 146 | | 146 | 241 |
| 133 | do. | 133 | 219 | 146.2 | Shiloh | | |
| 134 | do. | 134 | 138 | 147 | | 147 | 236 |
| 135 | do. | 135 | 050 | 148 | | 148 | 223 |
| 136 | do. | 136 | 46986 | 149 | | 149 | 206 |
| 137 | do. | 137 | 888 | 150 | | 150 | 198 |
| 138 | do. | 138 | 824 | 151 | | 151 | 188 |
| | | | | 151 | Allenhurst; end of traverse J | | |

Florida magnetic traverse K

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|------------|-----------------------------------|----------------|-----------------------------|-------|-----------------------|----------------|-----------------------------|
| 0 | Coronado, Fla., on the beach | | | 11 | Fla. 75 | 12 | 153 |
| 0 | | 1 | 47044 | 11.4 | Junction Fla. 57 & 75 | | |
| 0.5 to 0.7 | bridge | | | 12 | Fla. 75 | 13 | 161 |
| 1 | | 2 | 031 | 13 | do. | 14 | 156 |
| 2 | | 3 | 023 | 14 | do. | 15 | 138 |
| 2.3 | Junction U.S. 1; New Smyrna Beach | | | 15 | do. | 16 | 132 |
| 2.5 | R.R. crossing | | | 16 | do. | 17 | 129 |
| 3 | Fla. 75 | 4 | 46955 | 17 | do. | 18 | 118 |
| 4 | do. | 5 | 987 | 18 | do. | 19 | 194 |
| 5 | do. | 6 | 968 | 19 | do. | 20 | 338 |
| 6 | do. | 7 | 961 | 20 | do. | 21 | 47426 |
| 7 | do. | 8 | 008 | 21 | do. | 22 | 332 |
| 8 | do. | 9 | 049 | 21.5 | do. | 22a | 157 |
| 9 | do. | 10 | 075 | 22 | do. | 23 | 46994 |
| 10 | do. | 11 | 099 | 22.5 | do. | 24 | 861 |

Florida magnetic traverse K (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------------------------|----------------|-----------------------------|-------|------------------------------|----------------|-----------------------------|
| 23 | Fla. 75 | 25 | 760 | 52.8 | R.R. crossing | | |
| 24 | do. | 26 | 748 | 53 | Fla. 100 | 55 | 432 |
| 24.2 | Side road | | | 54 | do. | 56 | 459 |
| 25 | Fla. 75 | 27 | 642 | 55 | do. | 57 | 488 |
| 26 | do. | 28 | 640 | 56 | do. | 58 | 501 |
| 27 | do. | 29 | 611 | 57 | do. | 59 | 510 |
| 27.9 | R.R. crossing | | | 58 | do. | 60 | 534 |
| 28 | Fla. 75 | 30 | 547 | 59 | do. | 61 | 558 |
| 28.1 | Junction U.S. 17 (Deland, Fla.) | | | 60 | do. | 62 | 567 |
| 29 | Fla. 21 | 31 | 642 | 60.8 | Junction with Fla. 38 | | |
| 30 | do. | 32 | 654 | 61 | Fla. 38 | 63 | 597 |
| 30.8 | R.R. crossing | | | 62 | do. | 64 | 640 |
| 31 | Fla. 21 | 33 | 654 | 63 | do. | 65 | 642 |
| 31.4 | R.R. crossing | | | 64 | do. | 66 | 619 |
| 32 | Fla. 21 | 34 | 631 | 65 | do. | 67 | 595 |
| 33 | do. | 35 | 636 | 66 | do. | 68 | 46561 |
| 33.7 | St. Johns River | | | 67 | do. | 69 | 521 |
| 33.9 | Junction Fla. 100 | | | 68 | do. | 70 | 493 |
| 34 | Fla. 100 | 36 | 647 | 69 | do. | 71 | 555 |
| 35 | do. | 37 | 638 | 70 | do. | 72 | 544 |
| 36 | do. | 38 | 46622 | 71 | do. | 73 | 509 |
| 37 | do. | 39 | 637 | 71.3 | Junction U.S. 441; Weirsdale | | |
| 38 | do. | 40 | 648 | 71.4 | R.R. crossing | | |
| 39 | do. | 41 | 690 | 72 | Fla. 38 | 74 | 528 |
| 40 | do. | 42 | 706 | 73 | do. | 75 | 535 |
| 41 | do. | 43 | 692 | 73.4 | Side road | | |
| 42 | do. | 44 | 686 | 74 | Fla. 38 | 76 | 532 |
| 43 | do. | 45 | 670 | 74.7 | Side road | | |
| 44 | do. | 46 | 667 | 75 | Fla. 38 | 77 | 560 |
| 44.2 | Paisley | | | 76 | do. | 78 | 593 |
| 45 | Fla. 100 | 47 | 608 | 77 | do. | 79 | 610 |
| 46 | do. | 48 | 566 | 78 | do. | 80 | 598 |
| 47 | do. | 49 | 552 | 78.4 | R.R. crossing | | |
| 48 | do. | 50 | 517 | 78.5 | Junction Fla. 23 | | |
| 49 | do. | 51 | 518 | 79 | Fla. 38 | 81 | 599 |
| 50 | do. | 52 | 503 | 80 | do. | 82 | 612 |
| 51 | do. | 53 | 479 | 81 | do. | 83 | 654 |
| 51.2 | Road junction | | | 82 | do. | 84 | 647 |
| 52 | | 54 | 469 | 83 | do. | 85 | 630 |
| 52.7 | Junction Fla. 55, Altoona | | | 83.4 | Turned north; Pedro via 239 | | |

Florida magnetic traverse K (Cont'd.)

| Mines | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|------------------------|----------------|-----------------------------|-------|--|----------------|-----------------------------|
| 84 | Fla. 239 | 86 | 615 | 112 | Fla. 81 | 114 | 749 |
| 85 | do. | 87 | 578 | 113 | do. | 115 | 750 |
| 85.4 | Side road east | | | 114 | do. | 116 | 749 |
| 86 | Fla. 239 | 88 | 601 | 114.6 | R.R. crossing | | |
| 86.4 | Side road east | | | 114.7 | River | | |
| 87 | Fla. 239 | 89 | 621 | 115 | | 117 | 734 |
| 88 | do. | 90 | 600 | 115.5 | Junction U.S. 19; R.R. crossing; Dunnellon, Fla. | | |
| 89 | do. | 91 | 632 | 116 | Fla. 81 | 118 | 741 |
| 90 | do. | 92 | 688 | 117 | do. | 119 | 762 |
| 91 | do. | 93 | 758 | | | | |
| 91.5 | Turned west | | | 118 | Fla. 81 | 120 | 46777 |
| 92 | Fla. 239 | 94 | 46817 | 119 | do. | 121 | 775 |
| 93 | | 95 | 827 | 119.8 | Junction Fla. 16A & leave Fla. 81 | | |
| 93.5 | Curved north | | | 120 | Fla. 16A | 122 | 784 |
| 94 | | 96 | 897 | | | | |
| 95 | | 97 | 966 | 121 | do. | 123 | 767 |
| 95.3 | Turned west; dirt road | | | 122 | do. | 124 | 766 |
| 96 | | 98 | 47025 | 123 | do. | 125 | 762 |
| 97 | | 99 | 016 | 124 | do. | 126 | 752 |
| 98 | | 100 | 46977 | 125 | do. | 127 | 723 |
| 98.1 | Junction Fla. 74 | | | 126 | do. | 128 | 741 |
| 99 | do. | 101 | 931 | 127 | do. | 129 | 740 |
| 100 | do. | 102 | 885 | 128 | do. | 130 | 741 |
| 101 | do. | 103 | 831 | 129 | do. | 131 | 735 |
| 102 | do. | 104 | 738 | 130 | do. | 132 | 716 |
| 103 | do. | 105 | 747 | 130 | Fla. Power Co. plant | | |
| 104 | do. | 106 | 704 | 130.7 | Inglis | | |
| 104.3 | Junction Fla. 81 | | | 131 | Fla. 16A | 133 | 710 |
| 105 | Fla. 81 | 107 | 688 | 132 | do. | 134 | 709 |
| 106 | do. | 108 | 690 | 133 | do. | 135 | 691 |
| 107 | do. | 109 | 690 | 133 | Yankeetown | | |
| 108 | do. | 110 | 706 | 133.7 | | 136 | 708 |
| 109 | do. | 111 | 716 | 133.7 | End of line K | | |
| 110 | do. | 112 | 714 | | | | |
| 111 | do. | 113 | 744 | | | | |

Florida magnetic traverse K' (around York well)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------------------------|----------------|-----------------------------|-------|-----------------------|----------------|-----------------------------|
| 0.0 | Junction U.S. 41 & 19 & Fla. 74 | | | 14 | Fla. 16 | 14 | 065 |
| | Dunnellon | | | 14.5 | Side road from south | | |
| 0.9 | R.R. crossing | | | 15 | Fla. 16 | 15 | 065 |
| 1 | U.S. 41 & 19 | 1 | 46614 | 16 | do. | 16 | 059 |
| 2 | do. | 2 | 653 | 17 | do. | 17 | 073 |
| 3 | do. | 3 | 686 | 17.6 | Side road south | | |
| 3.7 | Side road to Rainbow Springs | | | 18 | Fla. 16 | 18 | 084 |
| 4 | U.S. 41 & 19 | 4 | 882 | 19 | R.R. 500' | 19 | 083 |
| 4.5 | Junction Fla. 16 | | | | south | | |
| 4.7 | R.R. underpass | | | 20 | R.R. 500' | 20 | 086 |
| | | | | | south, Fla. 16 | | |
| 5 | Fla. 16 | 5 | 928 | 21 | Fla. 16 | 21 | 112 |
| 6 | do. | 6 | 940 | | | | |
| 6.8 | R.R. underpass | | | 21.4 | R.R. crossing | | |
| 7 | | 7 | 948 | 22 | Fla. 16 | 22 | 47118 |
| 8 | Fla. 16 | 8 | 975 | 23 | do. | 23 | 141 |
| | | | | 23.2 | Junction Fla. 16 & 19 | | |
| 9 | do. | 9 | 980 | 24 | Fla. 16 | 24 | 118 |
| 10 | do. | 10 | 985 | | | | |
| 11 | do. | 11 | 47023 | 25 | Ocala | 25 | 47103 |
| 12 | do. | 12 | 028 | 25.3 | Junction U.S. 441 | | |
| 13 | do. | 13 | 049 | | | | |

Florida magnetic traverse L

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-----------------------|----------------|-----------------------------|-------|----------------------------|----------------|-----------------------------|
| 0 | Cedar Keys | 1 | 46697 | 13 | Fla. 13 | 14 | 841 |
| | Beach | | | 14 | do. | 15 | 848 |
| 1 | Fla. 13 | 2 | 723 | 15 | do. | 16 | 833 |
| 2 | do. | 3 | 733 | 16 | do. | 17 | 832 |
| 2.2 | Bridge do. | | | 17 | do. | 18 | 814 |
| 3 | Fla. 13 | 4 | 755 | | | | |
| 4 | do. | 5 | 749 | 18 | do. | 19 | 828 |
| 5 | do. | 6 | 787 | 19 | do. | 20 | 823 |
| 6 | do. | 7 | 796 | 20 | do. | 21 | 799 |
| 7 | do. | 8 | 803 | 21 | | 22 | 829 |
| 8 | do. | 9 | 811 | 21.3 | Side road south | | |
| 9 | | 10 | 816 | 21.7 | Junction Fla. 81 & 13 | | |
| 9.5 | Junction Fla. 13 & 77 | | | 22 | Fla. 13 | 23 | 816 |
| 10 | Fla. 13 | 11 | 853 | 22 | Otter Creek; R.R. crossing | | |
| 11 | do. | 12 | 837 | 23 | Fla. 13 | 24 | 834 |
| 12 | do. | 13 | 829 | 24 | do. | 25 | 840 |

Florida magnetic traverse L (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-------------------------------------|----------------|-----------------------------|-------|-------------------------------|----------------|-----------------------------|
| 25 | Fla. 13 | 26 | 859 | 55.9 | Cross road; village | | |
| 26 | do. | 27 | 873 | 56 | Fla. 47A | 57 | 47404 |
| 27 | do. | 28 | 882 | 57 | do. | 58 | 404 |
| 28 | do. | 29 | 896 | 58 | | 59 | 404 |
| 29 | do. | 30 | 918 | 58.9 | R.R. crossing; Irvine | | |
| 30 | do. | 31 | 46947 | 59 | | 60 | 431 |
| 31 | do. | 32 | 954 | 60 | | 61 | 443 |
| 32 | do. | 33 | 973 | 61 | | 62 | 463 |
| 32.4 | High-tension line | | | 61.4 | Junction Fla. 47A & U.S. | | 441 |
| 33 | | 34 | 965 | 62 | Fla. 47A | 63 | 472 |
| 33.5 | Junction Fla. 13, U.S. 19 & Fla. 19 | | | 62.2 | R.R. crossing | | |
| 33.6 | Bronson | | | 63 | Fla. 47A | 64 | 481 |
| 34 | Fla. 19 | 35 | 966 | 64 | do. | 65 | 459 |
| 35 | do. | 36 | 47016 | 65 | do. | 66 | 462 |
| 36 | do. | 37 | 050 | 66 | do. | 67 | 466 |
| 37 | do. | 38 | 071 | 66.7 | Side road | | |
| 38 | do. | 39 | 090 | 67 | Fla. 47A | 68 | 442 |
| 39 | do. | 40 | 122 | 67.8 | Junction Fla. 31 & 47A; Citra | | |
| 40 | do. | 41 | 153 | 68 | Fla. 47A | 69 | 417 |
| 41 | do. | 42 | 162 | 68.1 | R.R. crossing | | |
| 42 | do. | 43 | 195 | 69 | Fla. 47A | 70 | 421 |
| 43 | do. | 44 | 221 | 70 | do. | 71 | 399 |
| 44 | do. | 45 | 250 | 71 | do. | 72 | 390 |
| 45 | do. | 46 | 251 | 72 | do. | 73 | 380 |
| 45.8 | Junction U.S. 41 & 19 & Fla. 19 | | | 73 | do. | 74 | 403 |
| 46 | 47a Fla. 19 | 47 | 311 | 74 | do. | 75 | 421 |
| 46.3 | R.R. crossing; Williston | | | 75 | do. | 76 | 426 |
| 46.9 | R.R. crossing | | | 76 | do. | 77 | 421 |
| 47 | Fla. 19 | 48 | 302 | 77 | do. | 78 | 423 |
| 47.2 | Junction Fla. 19 & 47 | | | 78 | do. | 79 | 421 |
| 48 | Fla. 47A | 49 | 327 | 79 | do. | 80 | 424 |
| 49 | do. | 50 | 345 | 80 | | 81 | 397 |
| 50 | do. | 51 | 369 | 80.4 | Junction Fla. 47A & 244 | | |
| 51 | do. | 52 | 391 | 80.9 | Orange Springs | | |
| 52 | do. | 53 | 383 | 81 | | 82 | 391 |
| 53 | do. | 54 | 396 | 81.2 | Creek | | |
| 54 | do. | 55 | 391 | 82 | Fla. 47A | 83 | 47432 |
| 55 | do. | 56 | 47417 | 82.3 | Turned right onto sand road | | |
| | | | | 83 | | 84 | 423 |

Florida magnetic traverse L (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|----------------------------------|----------------|-----------------------------|
| 84 | | 85 | 414 | 115 | Fla. 28 | 115 | 264 |
| 85 | | 86 | 418 | 116 | do. | 116 | 264 |
| 86 | Side road north | 87 | 440 | 117 | do. | 117 | 303 |
| 87 | | 88 | 437 | 118 | do. | 118 | 330 |
| 87 | Road intersection; Kenwood, turned left | | | 119 | do. | 119 | 277 |
| 88 | Fla. 47a | 89 | 472 | 120 | do. | 120 | 224 |
| 88.1 | Turned right | | | 121 | do. | 121 | 189 |
| 89 | | 90 | 459 | 122 | do. | 122 | 072 |
| 90 | Fla. 47a | 91 | 450 | 123 | do. | 123 | 46929 |
| 91 | do. | 92 | 422 | 124 | do. | 124 | 895 |
| 92 | do. | 93 | 450 | 125 | do. | 125 | 864 |
| 93 | do. | 94 | 457 | 126 | do. | 126 | 839 |
| 94 | do. | 95 | 435 | 127 | do. | 127 | 820 |
| 95 | do. | 96 | 454 | 128 | do. | 128 | 815 |
| 96 | do. | 97 | 475 | 129 | do. | 129 | 819 |
| 97 | do. | 98 | 544 | 130 | do. | 130 | 818 |
| 98 | do. | 99 | 583 | 131 | do. | 131 | 837 |
| 99 | do. | 100 | 519 | 132 | do. | 132 | 824 |
| 100 | do. | 101 | 477 | 133 | do. | 133 | 839 |
| 101 | do. | 102 | 457 | 134 | do. | 134 | 854 |
| 102 | do. | 103 | 462 | 135 | do. | 135 | 864 |
| 102.2 | Cross road; pavement | | | 136 | do. | 136 | 869 |
| 103 | | 104 | 443 | 137 | do. | 137 | 835 |
| 103.4 | Cross road | | | 138 | do. | 138 | 847 |
| 104 | Fla. 47a | 105 | 425 | 138.4 | R.R. overpass | | |
| 104.1 | Junction Fla. 14; turned right | | | 138.8 | Junction U.S. 1 | | |
| 105 | Fla. 14 | 106 | 410 | 139 | Fla. 28 | 139 | 46810 |
| 106 | do. | 107 | 399 | 139.3 | Bunnell, turn left on Fla. 28 | | |
| 107 | do. | 108 | 354 | 140 | Fla. 28 | 140 | 819 |
| 108 | do. | 109 | 329 | 141 | do. | 141 | 823 |
| 109 | | 110 | 47196 | 142 | do. | 142 | 830 |
| 109 | Inside Palatka City limit | | | 143 | do. | 143 | 838 |
| 109.2 | Junction U.S. 17 | | | 144 | do. | 144 | 843 |
| 110 | Bridge St. Johns River | | | 144.3 | Side road south | | |
| 110.7 | U.S. 17 | 111 | 239 | 145 | Fla. 28 | 145 | 854 |
| 111.4 | Junction Fla. 14 & 28 & U.S. 17 | | | 146 | do. | 146 | 875 |
| 112 | U.S. 17 | 112 | 232 | 147 | do. | 147 | 899 |
| 113 | do. | 113 | 245 | 147.2 | Bridge to island | | |
| 114 | do. | 114 | 327 | 147.7 | Flagler Beach | | |
| 114.6 | Junction Fla. 28 & U.S. 17 | | | 147.8 | | 148 | 880 |
| | | | | 147.8 | Junction Fla. 140; end of line L | | |

Florida magnetic traverse M

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|-------|--------------------------------------|----------------|-----------------------------|
| 0 | Beach at Anastasia, Island east of St. Augustine | | | 26 | Fla. 14 | 25 | 345 |
| 0 | | 1 | 47639 | 27 | do. | 26 | 276 |
| 0.6 | Draw bridge | | | 27.8 | Road intersection | | |
| 0.8 | Junction Fla. 140 with U.S. 1 | | | 28 | Fla. 14 | 27 | 240 |
| 1 | St. Augustine, Fla. | | | 28.3 | R.R. crossing, E. Palatka | | |
| 2.8 | Junction U.S. 1 & Fla. 14 | | | 28.6 | Junction Fla. 28, U.S. 17, & Fla. 14 | | |
| 3 | Fla. 14 | 2 | 616 | 29 | Fla. 14 | 28 | 252 |
| 3.5 | R.R. crossing | | | 30 | St. Johns River | | |
| 4 | Fla. 14 | 3 | 605 | 30.5 | Palatka | | |
| 5 | do. | 4 | 590 | 31.4 | R.R. crossing | | |
| 6 | do. | 5 | 564 | 32 | Fla. 14 | 29 | 309 |
| 7 | do. | 6 | 521 | 32.3 | Junction Fla. 28 & U.S. 17 | | |
| 8 | do. | 7 | 503 | 33 | Fla. 28 | 30 | 387 |
| 9 | do. | 8 | 508 | 34 | do. | 31 | 430 |
| 10 | do. | 9 | 503 | 35 | do. | 32 | 457 |
| 10.2 | R.R. crossing | | | 36 | do. | 33 | 467 |
| 11 | Fla. 14 | 10 | 500 | 37 | do. | 34 | 459 |
| 11.9 | Side road north | | | 38 | do. | 35 | 450 |
| 12 | Fla. 14 | 11 | 496 | 39 | do. | 36 | 452 |
| 13 | do. | 12 | 487 | 40 | do. | 37 | 451 |
| 14 | do. | 13 | 508 | 41 | do. | 38 | 456 |
| 15 | do. | 14 | 541 | 42 | do. | 39 | 476 |
| 16 | do. | 15 | 515 | 43 | do. | 40 | 501 |
| 16.7 | R.R. crossing | | | 44 | do. | 41 | 534 |
| 16.9 | Side road north | | | 45 | do. | 42 | 575 |
| 17 | Fla. 14 | 16 | 528 | 46 | do. | 43 | 595 |
| 18 | do. | 17 | 506 | 47 | do. | 44 | 597 |
| 18.1 | River | | | 48 | do. | 45 | 616 |
| 19 | Fla. 14 | 18 | 488 | 49 | do. | 46 | 624 |
| 19.7 | Hastings | | | 49.6 | Cross road; Grandin | | |
| 20 | Fla. 14 | 19 | 451 | 50 | Fla. 28 | 47 | 47639 |
| 20.6 | R.R. crossing | | | 51 | do. | 48 | 649 |
| 21 | Fla. 14 | 20 | 468 | 52 | do. | 49 | 644 |
| 22 | do. | 21 | 455 | 52.7 | Turned south off Fla. 28 | | |
| 22.1 | Side road north | | | 53 | Fla. 267 | 50 | 647 |
| 23 | Fla. 14 | 22 | 47414 | 54 | do. | 51 | 646 |
| 24 | do. | 23 | 378 | 55 | do. | 52 | 632 |
| 24.2 | R.R. crossing | | | 56 | do. | 53 | 621 |
| 25 | Fla. 14 | 24 | 353 | 57 | do. | 54 | 613 |
| | | | | 58 | do. | 55 | 606 |

Florida magnetic traverse M (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|----------------------|----------------|-----------------------------|-------|-------------------|----------------|-----------------------------|
| 58.1 | Cross road | | | 83 | Fla. 14 | 79 | 349 |
| 58.4 | Melrose | | | 84 | do. | 80 | 334 |
| 59 | Fla. 267 | 56 | 583 | 85 | do. | 81 | 320 |
| 60 | do. | 57 | 575 | 86 | do. | 82 | 298 |
| 61 | do. | 58 | 570 | 87 | do. | 83 | 265 |
| 62 | do. | 59 | 571 | 88 | do. | 84 | 259 |
| 62.2 | Cross road | | | 89 | do. | 85 | 235 |
| 63 | Fla. 267 | 60 | 574 | 90 | do. | 86 | 197 |
| 64 | do. | 61 | 557 | 91 | do. | 87 | 170 |
| 64.2 | R.R. junction Fla. | 31 | | 92 | do. | 88 | 153 |
| 65 | Fla. 267 | 62 | 551 | 93 | do. | 89 | 125 |
| 66 | do. | 63 | 531 | 94 | do. | 90 | 089 |
| 67 | do. | 64 | 527 | 94.2 | Cross road | | |
| 68 | do. | 65 | 508 | 95 | Fla. 14 | 91 | 090 |
| 69 | do. | 66 | 502 | 95.2 | Junction U.S. | 41 | |
| 70 | do. | 67 | 493 | 95.3 | Newberry | | |
| 71 | do. | 68 | 480 | 95.5 | R.R. crossing | | |
| 72 | do. | 69 | 455 | 96 | Fla. 14 | 92 | 080 |
| 73 | do. | 70 | 457 | 97 | do. | 93 | 074 |
| 73.3 | Side road south | | | 98 | do. | 94 | 062 |
| 74 | Fla. 267 | 71 | 454 | 99 | do. | 95 | 029 |
| 75 | do. | 72 | 455 | 99.7 | High-tension line | | |
| 76 | do. | 73 | 419 | 100 | Fla. 14 | 96 | 006 |
| 76.1 | Junction Fla. | 14 | | 101 | do. | 97 | 46993 |
| 76.3 | R.R. junction Fla. | 13 | | 102 | do. | 98 | 995 |
| 77 | Within city limits | | | 103 | do. | 99 | 47003 |
| 77.3 | Gainesville, Fla. | | | 104 | do. | 100 | 46993 |
| 77.5 | R.R. crossing | | | 105 | do. | 101 | 989 |
| 78 | Fla. 267 | 74 | 47384 | 106 | do. | 102 | 47017 |
| 78 | Junction with U.S. | 441 | | 107 | do. | 103 | 028 |
| | Univ. of Fla. campus | | | 108 | do. | 104 | 009 |
| 79 | Fla. 14 | 75 | 406 | 108.4 | Junction Fla. | 77, Trenton | |
| 80 | do. | 76 | 406 | 109 | Fla. 14 | 105 | 46989 |
| 81 | do. | 77 | 377 | 110 | do. | 106 | 940 |
| 81.3 | Side road north | | | 111 | do. | 107 | 911 |
| 82 | | 78 | 320 | | | | |

Florida magnetic traverse M (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-------------------------------------|----------------|-----------------------------|-------|-------------------------|----------------|-----------------------------|
| 112 | Fla. 14 | 108 | 888 | 132 | U.S. 19 | 127 | 936 |
| 113 | do. | 109 | 880 | 133 | do. | 128 | 955 |
| 114 | do. | 110 | 858 | 134 | do. | 129 | 980 |
| 115 | do. | 111 | 859 | 135 | do. | 130 | 47023 |
| 116 | do. | 112 | 852 | 136 | do. | 131 | 068 |
| 116.3 | Junction U.S. 19 | | | 137 | do. | 132 | 47094 |
| 116.5 | R.R. crossing | | | 138 | do. | 133 | 163 |
| 117 | Suwannee River, fill and guard rail | | | 139 | do. | 134 | 265 |
| 118 | U.S. 19 | 113 | 845 | 140 | do. | 135 | 317 |
| 119 | do. | 114 | 831 | 141 | do. | 136 | 344 |
| 120 | do. | 115 | 836 | 142 | do. | 137 | 345 |
| 120.4 | Junction Fla. 50; Oldtown | | | 142.3 | Turned left to Fla. 295 | | |
| 121 | U.S. 19 | 116 | 844 | 143 | Fla. 295 | 138 | 333 |
| 122 | do. | 117 | 859 | 144 | do. | 139 | 313 |
| 123 | do. | 118 | 847 | 145 | do. | 140 | 293 |
| 124 | do. | 119 | 863 | 145.6 | R.R. crossing | | |
| 125 | do. | 120 | 855 | 146 | Fla. 295 | 141 | 270 |
| 126 | do. | 121 | 861 | 147 | do. | 142 | 242 |
| 127 | do. | 122 | 871 | 147.5 | Jenna | | |
| 128 | do. | 123 | 879 | 148 | Fla. 295 | 143 | 238 |
| 129 | do. | 124 | 875 | 149 | | 144 | 262 |
| 130 | Cross City | 125 | 874 | 149.5 | | 145 | 230 |
| 130.7 | Cross road | | | 149.5 | Steward; end of line M | | |
| 130.9 | Shamrock | | | | | | |
| 131 | U.S. 19 | 126 | 907 | | | | |

Florida magnetic traverse N

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-----------------------------|----------------|-----------------------------|-------|-----------------|----------------|-----------------------------|
| 0 | 1 mile North Econfina River | | | 9 | Fla. 66 | 10 | 759 |
| 0 | Fla. 66 | 1 | 47790 | 10 | do. | 11 | 764 |
| 1 | Econfina River | 2 | 792 | 11 | do. | 12 | 754 |
| 2 | Fla. 66 | 3 | 783 | 12 | do. | 13 | 745 |
| 3 | do. | 4 | 790 | 12.3 | R.R. crossing | | |
| 4 | do. | 5 | 791 | 12.8 | Creek | | |
| 5 | do. | 6 | 783 | 13 | Hampton Springs | 14 | 747 |
| 6 | do. | 7 | 785 | 14 | Fla. 66 | 15 | 774 |
| 7 | do. | 8 | 782 | 15 | do. | 16 | 780 |
| 8 | do. | 9 | 759 | 16 | do. | 17 | 771 |

Florida magnetic traverse N (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-------------------------|----------------|-----------------------------|---------------|------------------------|----------------|-----------------------------|
| 17 | Fla. 66 | 18 | 770 | 46 | Fla. 5A | 47 | 891 |
| 17.9 | Junction U.S. | 19 | | 47 | do. | 48 | 847 |
| 18 | Fla. 66 | 19 | 758 | 47 | Mayo | | |
| 18.2 | R.R. crossing | | | 48 | Fla. 5A | 49 | 848 |
| 18.4 | Junction Fla. 5A, Perry | | | 49 | do. | 50 | 788 |
| 19 | Fla. 5A | 20 | 763 | 50 | do. | 51 | 773 |
| 20 | do. | 21 | 781 | 51 | do. | 52 | 735 |
| 21 | do. | 22 | 775 | 51.8 | Cross road | | |
| 22 | do. | 23 | 772 | 52 | Fla. 5A | 53 | 745 |
| 22.3 | R.R. crossing | | | 53 | do. | 54 | 722 |
| 22.8 | Side road south | | | 54 | do. | 55 | 47689 |
| 23 | Fla. 5A | 24 | 758 | 55 | do. | 56 | 681 |
| 23.7 | Side road south | | | 56 | do. | 57 | 636 |
| 24 | Fla. 5A | 25 | 773 | 57 | do. | 58 | 641 |
| 25 | do. | 26 | 799 | 58 | do. | 59 | 597 |
| 25.5 | R.R. crossing | | | 59 | do. | 60 | 580 |
| 26 | Fla. 5A | 27 | 47815 | 60 | do. | 61 | 541 |
| 26.9 | R.R. crossing | | | 61 | do. | 62 | 526 |
| 27 | Fla. 5A | 28 | 816 | 62 | do. | 63 | 522 |
| 27.6 | River | | | 63 | do. | 64 | 514 |
| 28 | | 29 | 823 | 64 | do. | 65 | 534 |
| 29 | Fla. 5A | 30 | 828 | 64.7 | Suwannee River | | |
| 30 | do. | 31 | 830 | 64.8 | R.R.; junction Fla. 50 | | |
| 31 | do. | 32 | 831 | 64.9 | Branford | | |
| 32 | do. | 33 | 841 | 65 | Fla. 5A | 66 | 556 |
| 33 | do. | 34 | 856 | 66 | do. | 67 | 567 |
| 34 | do. | 35 | 869 | 67 | do. | 68 | 568 |
| 35 | do. | 36 | 892 | 68 | do. | 69 | 572 |
| 36 | do. | 37 | 917 | 69 | do. | 70 | 590 |
| 37 | do. | 38 | 923 | 69 | Junction Fla. 77 | | |
| 38 | do. | 39 | 919 | 70 | Fla. 5A | 71 | 578 |
| 39 | do. | 40 | 929 | 70 | Phosphate mine | | |
| 40 | do. | 41 | 900 | 71 | Fla. 5A | 72 | 572 |
| 41 | do. | 42 | 922 | 72 | do. | 73 | 564 |
| 42 | do. | 43 | 923 | 73 | do. | 74 | 547 |
| 42.1 | Side road north | | | 73.6 | River | | |
| 43 | Fla. 5A | 44 | 924 | 73.9 | High-tension line | | |
| 44 | do. | 45 | 889 | 74 | Fla. 5A | 75 | 519 |
| 45 | do. | 46 | 915 | 75 | do. | 76 | 481 |
| 45.6 | R.R. crossing | | | 75.7 and 75.8 | R.R. crossing ("Y") | | |

Florida magnetic traverse N (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|---------------------------------|----------------|-----------------------------|
| 76 | Fla. 5A | 77 | 442 | 105 | Providence | 106 | 303 |
| 77 | do. | 78 | 397 | 105.8 | Side road south | | |
| 78 | do. | 79 | 330 | 106 | Fla. 56 | 107 | 282 |
| 78.6 | Fort White | | | 106 | Junction Fla. 28; R.R. crossing | | |
| 78.9 | Dirt road (cut-off) | | | 106.1 | Junction Fla. 28 & 49 | | |
| 79 | Fla. 236 | 80 | 47303 | 106.2 | Lake Butler | | |
| 80 | do. | 81 | 307 | 106.5 | R.R. crossing | | |
| 81 | do. | 82 | 294 | 107 | Fla. 28 | 108 | 47327 |
| 82 | do. | 83 | 285 | 107.1 | Junction Fla. 28 & 49 | | |
| 83 | do. | 84 | 301 | 108 | Fla. 28 | 109 | 339 |
| 84 | do. | 85 | 288 | 109 | do. | 110 | 371 |
| 85 | do. | 86 | 259 | 110 | do. | 111 | 417 |
| 85.6 | Junction dirt road, U.S. 41, turned north | | | 110.7 | New River | | |
| 86 | U.S. 41 | 87 | 283 | 111 | Fla. 28 | 112 | 510 |
| 87 | do. | 88 | 313 | 112 | do. | 113 | 568 |
| 88 | do. | 89 | 343 | 113 | do. | 114 | 605 |
| 89 | do. | 90 | 393 | 114 | do. | 115 | 639 |
| 90 | do. | 91 | 454 | 115 | do. | 116 | 641 |
| 90.3 | Junction U.S. 41, Fla. 56, turned right | | | 116 | do. | 117 | 610 |
| 91 | Fla. 56 | 92 | 433 | 117 | do. | 118 | 641 |
| 92 | do. | 93 | 415 | 118 | do. | 119 | 657 |
| 93 | do. | 94 | 369 | 119 | do. | 120 | 664 |
| 93.5 | Providence | | | 120 | do. | 121 | 690 |
| 94 | do. | 95 | 346 | 121 | do. | 122 | 709 |
| 95 | do. | 96 | 326 | 121.6 | Junction Fla. 13; turned left | | |
| 96 | do. | 97 | 305 | 121.7 | Starke, Fla. | | |
| 97 | do. | 98 | 327 | 122 | Fla. 28 | 123 | 696 |
| 98 | do. | 99 | 340 | 122.1 | Junction Fla. 48, turned right | | |
| 99 | do. | 100 | 349 | 122.2 | R.R. crossing | | |
| 100 | do. | 101 | 337 | 123 | Fla. 48 | 124 | 754 |
| 101 | do. | 102 | 360 | 124 | do. | 125 | 788 |
| 102 | do. | 103 | 369 | 125 | do. | 126 | 805 |
| 103 | do. | 104 | 353 | 126 | do. | 127 | 841 |
| 104 | do. | 105 | 320 | 127 | do. | 128 | 852 |
| | | | | 128 | do. | 129 | 868 |

Florida magnetic traverse N (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|---|---------------------------------|----------------|-----------------------------|
| 129 | Fla. 48 | 130 | 862 | 153.3 | E. bank St. Johns River | | |
| 130 | do. | 131 | 864 | 155.3 | Fla. 48 | 155 | 812 |
| 131 | do. | 132 | 882 | 155.5 | Cross road | | |
| 132 | do. | 133 | 887 | 156 | Fla. 48 | 156 | 799 |
| 133 | do. | 134 | 883 | 157 | do. | 157 | 782 |
| 134 | do. | 135 | 47867 | 158 | do. | 158 | 47768 |
| 135 | do. | 136 | 875 | 159 | do. | 159 | 755 |
| 136 | do. | 137 | 879 | 160 | do. | 160 | 751 |
| 136.1 | Cross road | | | 161 | do. | 161 | 723 |
| 137 | Fla. 48 | 138 | 878 | 162 | do. | 162 | 696 |
| 138 | do. | 139 | 878 | 163 | do. | 163 | 679 |
| 139 | do. | 140 | 882 | 164 | do. | 164 | 688 |
| 140 | do. | 141 | 867 | 164.4 | Cross road | | |
| 141 | do. | 142 | 852 | 165 | Fla. 48 | 165 | 683 |
| 141.4 | Penney Farms | | | 166 | do. | 166 | 673 |
| 142 | Fla. 48 | 143 | 857 | 167 | do. | 167 | 674 |
| 143 | do. | 144 | 846 | 168 | do. | 168 | 670 |
| 144 | do. | 145 | 846 | 169 | do. | 169 | 653 |
| 145 | do. | 146 | 828 | 170 | do. | 170 | 616 |
| 146 | do. | 147 | 854 | 170.3 | Side road south | | |
| 147 | do. | 147 | 854 | 171 | Fla. 48 | 171 | 594 |
| 147 | do. | 148 | 844 | 172 | do. | 172 | 589 |
| 148 | do. | 149 | 807 | 173 | do. | 173 | 584 |
| 148.5 | Junction U.S. 17 | | | 174 | do. | 174 | 600 |
| 149 | Fla. 48 | 150 | 795 | 175 | do. | 175 | 594 |
| 149.2 | R.R. crossing | | | 175.5 | Side road north | | |
| 149.6 | Junction U.S. 17 & Fla. 48; turned right; Green Cove Springs | | | 175.8 | R.R. crossing | | |
| 150 | Fla. 48 | 151 | 842 | 176 | Fla. 48 | 176 | 574 |
| 150.3 | Side road south | | | 176 | Junction U.S. 1 | | |
| 151 | Fla. 48 | 152 | 841 | 177 | City limit, St. Augustine | | |
| 152 | do. | 153 | 877 | 177.5 | St. Augustine | 177 | 605 |
| 153 | do. | 154 | 823 | 177.9 | Left turn onto bridge, Fla. 140 | | |
| 153 | W. bank St. Johns River | | | 178.8 | Fla. 140 | 178 | 639 |
| 153.5 | St. Johns River | | | Same location on beach as station 1 line M | | | |

Florida magnetic traverse 0

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|-------|--|----------------|-----------------------------|
| 0 | 63rd and Dunnellon Rd. at Yankeetown; at AK 32 bench mark | | | 29 | Fla. 74 | 30 | 46729 |
| 0 | Fla. 16A | 0 | 46710 | 30 | do. | 31 | 779 |
| 1.1 | West of AK 32, entrance to Bonita Club | | | 31 | do. | 32 | 806 |
| 1.0 | East of AK 32 | 2 | 741 | 32 | do. | 33 | 846 |
| 2 | Fla. 16A-east | 3 | 757 | 33 | do. | 34 | 884 |
| 3 | Inglis | 4 | 717 | 34 | do. | 35 | 911 |
| 4 | Fla. 16A | 5 | 755 | 35 | do. | 36 | 958 |
| 5 | do. | 6 | 758 | 36 | do. | 37 | 993 |
| 6 | do. | 7 | 762 | 37 | do. | 38 | 47018 |
| 7 | do. | 8 | 766 | 38 | do. | 39 | 033 |
| 8 | Cattle guard | | | 39 | do. | 40 | 052 |
| 8.05 | do. | 9 | 774 | 40 | do. | 41 | 067 |
| 9 | do. | 10 | 769 | 40 | At Ocala airport, 500' E. of hangar | | |
| 10 | do. | 11 | 777 | 40.95 | | 42 | 048 |
| 11 | do. | 12 | 767 | 40.95 | Center of field across road from Ocala Sheet Metal Works | | |
| 11.95 | Marion-Levy Colins | | | 41.7 | Ocala Court House | | |
| 12 | Fla. 16A | 13 | 782 | 43.2 | Fla. 19 | 43 | 112 |
| 13 | do. | 14 | 793 | 44 | do. | 44 | 114 |
| 14 | do. | 15 | 787 | 45 | do. | 45 | 134 |
| 15 | do. | 16 | 766 | 46 | do. | 46 | 163 |
| 16 | do. | 17 | 763 | 47 | do. | 47 | 167 |
| 16.7 | W. edge of Dunnellon | 18 | 730 | 47 | Just west of Silver Springs | | |
| 18.2 | Seaboard Airline R.R. crossing | | | 48 | | 48 | 213 |
| 18.4 | Fla. 81 | 19 | 743 | 49 | Fla. 19 | 49 | 211 |
| 19 | do. | 20 | 782 | 50 | do. | 50 | 185 |
| 20 | do. | 21 | 772 | 51 | do. | 51 | 167 |
| 21 | do. | 22 | 775 | 52 | do. | 52 | 122 |
| 22 | do. | 23 | 746 | 53 | do. | 53 | 076 |
| 23 | do. | 24 | 745 | 54 | do. | 54 | 021 |
| 24 | do. | 25 | 745 | 55 | do. | 55 | 46973 |
| 25 | do. | 26 | 724 | 56 | do. | 56 | 914 |
| 26 | do. | 27 | 720 | 57 | do. | 57 | 875 |
| 27 | do. | 28 | 712 | 58 | do. | 58 | 833 |
| 28 | do. | 29 | 698 | 59 | do. | 59 | 800 |
| | | | | 60 | do. | 60 | 784 |

Florida magnetic traverse 0 (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---|----------------|-----------------------------|--------|---|----------------|-----------------------------|
| 60 | U.S.E.D. BMGW27, Lake Bryant Ranger Station | | | 96 | U.S. 17 | 96 | 46181 |
| 62 | Fla. 19 | 62 | 46772 | 97 | do. | 97 | 218 |
| 63 | do. | 63 | 772 | 98 | do. | 98 | 203 |
| 64 | do. | 64 | 793 | 99 | do. | 99 | 068 |
| 65 | do. | 65 | 820 | 100 | do. | 100 | 926 |
| 66 | do. | 66 | 825 | 101 | do. | 101 | 754 |
| 67 | do. | 67 | 823 | 101 | At junction U.S. 17 & 92; 500' west of intersection | | |
| 68 | do. | 68 | 834 | 101 | 101A | 101A | 778 |
| 69 | do. | 69 | 813 | 101 | 101A is 700' east of highway intersection | | |
| 70 | do. | 70 | 836 | 102 | U.S. 92 | 102 | 756 |
| 71 | do. | 71 | 774 | 103 | do. | 103 | 797 |
| 72 | do. | 72 | 758 | 104 | do. | 104 | 829 |
| 73 | do. | 73 | 741 | 105 | do. | 105 | 845 |
| 74 | do. | 74 | 746 | 106 | do. | 106 | 874 |
| 75 | do. | 75 | 738 | 107 | do. | 107 | 789 |
| 76 | do. | 76 | 738 | 108 | do. | 108 | 721 |
| 77 | do. | 77 | 736 | 109 | do. | 109 | 665 |
| 78 | do. | 78 | 742 | 110 | do. | 110 | 652 |
| 78.9 | Junction Fla. 19 & 55 at Astor Park | | | 111 | do. | 111 | 649 |
| 79 | Fla. 19 | 79 | 747 | 112 | do. | 112 | 654 |
| 80 | do. | 80 | 762 | 113 | do. | 113 | 654 |
| 81 | do. | 81 | 751 | 114 | do. | 114 | 673 |
| 82 | do. | 82 | 783 | 115 | do. | 115 | 670 |
| 82 | Astor | | | 116 | do. | 116 | 685 |
| 83 | do. | 83 | 855 | 117 | do. | 117 | 686 |
| 83.5 | Bridge across St. Johns River | | | 118 | do. | 118 | 728 |
| 84 | Fla. 19 | 84 | 950 | 119 | do. | 119 | 713 |
| 85 | do. | 85 | 926 | 119 | Opposite Gun Club | | |
| 86 | do. | 86 | 903 | 120 | do. | 120 | 769 |
| 87 | do. | 87 | 878 | 121.8 | F.E.C. R.R. crossing | | |
| 88.1 | do. | 88 | 830 | 121.35 | U.S. 92, edge of town | | |
| 89 | U.S. 17 | 89 | 785 | 122.3 | do. | 122 | 809 |
| 90 | do. | 90 | 771 | 122.3 | Edge of Halifax River, made lands | | |
| 91 | do. | 91 | 784 | | | | |
| 92 | do. | 92 | 804 | | | | |
| 93 | do. | 93 | 885 | | | | |
| 93.5 | do. | 93a | 934 | | | | |
| 94 | DeLeon Spgs. | 94 | 47006 | | | | |
| 95 | U.S. 17 | 95 | 112 | | | | |

Florida magnetic traverse P

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--|----------------|-----------------------------|-------|------------------------|----------------|-----------------------------|
| 0 | Fla. 78 | 1 | 47574 | 22.7 | Cross road | | |
| 0 | At Atlantic Beach, reinforced concrete wall along beach | | | 23 | U.S. 90 | 20 | 47771 |
| 1 | | 2 | 713 | 24 | do. | 21 | 775 |
| 1.5 | Side road north | | | 25 | do. | 22 | 785 |
| 2 | Fla. 78 | 3 | 716 | 26 | do. | 23 | 787 |
| 2.7 | Draw bridge | | | 27 | do. | 24 | 785 |
| 3 | Fla. 78 | 4 | 706 | 28 | do. | 25 | 774 |
| 4 | do. | 5 | 712 | 29 | do. | 26 | 726 |
| 5 | do. | 6 | 710 | 30 | do. | 27 | 749 |
| 6 | do. | 7 | 699 | 31 | do. | 28 | 748 |
| 7 | do. | 8 | 712 | 32 | do. | 29 | 791 |
| 8 | do. | 9 | 719 | 33 | do. | 30 | 873 |
| 8.1 | Side road north | | | 34 | do. | 31 | 895 |
| 9 | Fla. 78 | 10 | 716 | 35 | do. | 32 | 893 |
| 10 | do. | 11 | 719 | 36 | do. | 33 | 853 |
| 11 | do. | 12 | 743 | 37 | do. | 34 | 783 |
| 12 | do. | 13 | 754 | 37.7 | R.R. crossing; Baldwin | | |
| 12.7 | Bridge | | | 37.8 | Junction Fla. 13 | | |
| 12.9 | Cross road | | | 38 | U.S. 90 | 35 | 680 |
| 13 | Fla. 78 | 14 | 747 | 39 | do. | 36 | 639 |
| 13.6 | Bridge | | | 40 | do. | 37 | 630 |
| 14 | Fla. 78 | 15 | 740 | 41 | do. | 38 | 605 |
| 15 | do. | 16 | 753 | 41.6 | R.R. overpass | | |
| 15.2 | Side road south | | | 42 | U.S. 90 | 39 | 597 |
| 16 | Fla. 78 | 17 | 723 | 43 | do. | 40 | 587 |
| 16 | Junction U.S. 1; right turn | | | 44 | do. | 41 | 601 |
| 16.8 | Left turn | | | 45 | do. | 42 | 601 |
| 17 | | 18 | 754 | 46 | do. | 43 | 609 |
| 17 | South Jacksonville | | | 47 | do. | 44 | 581 |
| 17.3 | S. bank St. Johns River | | | 47 | Macclenny | | |
| 17.9 | N. bank St. Johns River; junction U.S. 17 | | | 48 | U.S. 90 | 45 | 631 |
| 18.3 | Junction U.S. 90, left turn; heart of Jacksonville, Fla. | | | 48.3 | River | | |
| 21.7 | U.S. 90 | 19 | 734 | 49 | U.S. 90 | 46 | 631 |
| | | | | 49.3 | Side road north | | |
| | | | | 50 | U.S. 90 | 47 | 638 |

Florida magnetic traverse P (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|-------------------------------|----------------|-----------------------------|-------|----------------------|----------------|-----------------------------|
| 51 | U.S. 90 | 48 | 47641 | 84 | U.S. 90 | 81 | 786 |
| 52 | do. | 49 | 650 | 85 | do. | 82 | 723 |
| 53 | do. | 50 | 646 | 86 | do. | 83 | 851 |
| 54 | do. | 51 | 640 | 87 | do. | 84 | 895 |
| 55 | do. | 52 | 636 | 88 | do. | 85 | 918 |
| 55.8 | R.R. overpass | | | 89 | do. | 86 | 939 |
| 56 | U.S. 90 | 53 | 617 | 90 | do. | 87 | 934 |
| 56.5 | Sanderson | | | 91 | do. | 88 | 928 |
| 57 | U.S. 90 | 54 | 611 | 92 | do. | 89 | 923 |
| 58 | do. | 55 | 603 | 92.5 | Cross road; Wellborn | | |
| 59 | do. | 56 | 585 | 93 | U.S. 90 | 90 | 900 |
| 60 | do. | 57 | 580 | 94 | do. | 91 | 869 |
| 61 | do. | 58 | 585 | 95 | do. | 92 | 860 |
| 62 | do. | 59 | 625 | 96 | do. | 93 | 823 |
| 63 | do. | 60 | 698 | 97 | do. | 94 | 818 |
| 64 | do. | 61 | 777 | 98 | do. | 95 | 820 |
| 65 | do. | 62 | 866 | 98 | Houston | | |
| 66 | do. | 63 | 910 | 99 | U.S. 90 | 96 | 858 |
| 66.6 | Olustee | | | 100 | do. | 97 | 875 |
| 67 | U.S. 90 | 64 | 939 | 100.6 | High-tension line | | |
| 68 | do. | 65 | 939 | 101 | U.S. 90 | 98 | 893 |
| 69 | do. | 66 | 934 | 102 | do. | 99 | 893 |
| 70 | do. | 67 | 929 | 103 | do. | 100 | 892 |
| 71 | do. | 68 | 894 | 103 | R.R. crossing | | |
| 72 | do. | 69 | 842 | 103.7 | Junction Fla. 50 | | |
| 73 | do. | 70 | 784 | 104 | Live Oak | | |
| 74 | do. | 71 | 750 | 105 | | 101 | 921 |
| 75 | do. | 72 | 718 | 105.4 | R.R. crossing | | |
| 76 | do. | 73 | 702 | 106 | U.S. 90 | 102 | 953 |
| 77 | do. | 74 | 673 | 107 | do. | 103 | 993 |
| 77.4 | Junction Fla. | 28 | | 108 | do. | 104 | 48032 |
| 77.5 | R.R. crossing | | | 109 | do. | 105 | 064 |
| 78 | U.S. 90 | 75 | 678 | 110 | do.(Fla.1) | 106 | 100 |
| 79 | do. | 76 | 653 | 111 | do. | 107 | 112 |
| 79.5 | Lake City; junction with U.S. | 41 | | 112 | do. | 108 | 122 |
| 80 | U.S. 90 | 77 | 47653 | 113 | do. | 109 | 137 |
| 80.2 | R.R. crossing | | | 114 | do. | 110 | 140 |
| 81 | U.S. 90 | 78 | 659 | 114.1 | Falmouth | | |
| 82 | do. | 79 | 676 | 115 | U.S. 90 | 111 | 156 |
| 83 | do. | 80 | 734 | 116 | do. | 112 | 127 |

Florida magnetic traverse P (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|--------------------------|----------------|-----------------------------|-------|---------------------------|----------------|-----------------------------|
| 117 | U.S. 90 | 113 | 129 | 146 | U.S. 90 | 142 | 768 |
| 117.3 | Suwannee River | | | 147 | do. | 143 | 795 |
| 118 | U.S. 90 | 114 | 107 | 147.1 | Junction Fla. 35 | | |
| 119 | do. | 115 | 099 | 148 | U.S. 90 | 144 | 772 |
| 119.6 | R.R. overpass | | | 148 | R.R. crossing; Greenville | | |
| 120 | U.S. 90 | 116 | 089 | 148.1 | Junction Fla. 35 | | |
| 121 | do. | 117 | 106 | 149 | U.S. 90 | 145 | 761 |
| 122 | do. | 118 | 065 | 150 | do. | 146 | 777 |
| 123 | do. | 119 | 039 | 151 | do. | 147 | 780 |
| 124 | do. | 120 | 015 | 152 | do. | 148 | 796 |
| 125 | do. | 121 | 47985 | 153 | do. | 149 | 808 |
| 125.7 | Cross road; Lee | | | 154 | do. | 150 | 811 |
| 126 | U.S. 90 | 122 | 945 | 154.3 | Aucilla River | | |
| 127 | do. | 123 | 911 | 155 | U.S. 90 | 151 | 838 |
| 128 | do. | 124 | 898 | 156 | do. | 152 | 852 |
| 129 | do. | 125 | 849 | 156.2 | Junction Fla. 42 | | |
| 130 | do. | 126 | 827 | 157 | U.S. 90 | 153 | 862 |
| 131 | do. | 127 | 830 | 158 | do. | 154 | 884 |
| 132 | do. | 128 | 824 | 159 | do. | 155 | 925 |
| 133 | do. | 129 | 792 | 160 | do. | 156 | 956 |
| 133.5 | R.R. crossing | | | 161 | do. | 157 | 977 |
| 133.8 | Cross road | | | 162 | do. | 158 | 48025 |
| 134 | U.S. 90 | 130 | 723 | 163 | do. | 159 | 017 |
| 134 | Junction Fla. 9, Madison | | | 163.7 | R.R. crossing | | |
| 135 | | 131 | 753 | 164 | U.S. 90 | 160 | 47974 |
| 136 | U.S. 90 | 132 | 47753 | 165 | do. | 161 | 48026 |
| 137 | do. | 133 | 771 | 166 | do. | 162 | 016 |
| 138 | do. | 134 | 772 | 166.1 | R.R. underpass | | |
| 139 | do. | 135 | 786 | 167 | U.S. 90 | 163 | 001 |
| 140 | do. | 136 | 769 | 168 | do. | 164 | 47987 |
| 141 | do. | 137 | 740 | 169 | do. | 165 | 984 |
| 142 | do. | 138 | 750 | 170 | do. | 166 | 985 |
| 143 | do. | 139 | 774 | 171 | do. | 167 | 962 |
| 144 | do. | 140 | 759 | 172 | do. | 168 | 974 |
| 145 | do. | 141 | 748 | 173 | do. | 169 | 947 |

Florida magnetic traverse P (Cont'd.)

| Miles | Road | Station number | Vertical magnetic intensity | Miles | Road | Station number | Vertical magnetic intensity |
|-------|---------------|-------------------|-----------------------------------|-------|--------------------------------|-------------------|-----------------------------------|
| 173.6 | Cross road | | | 182 | U.S. 90 | 178 | 861 |
| 174 | U.S. 90 | 170 | 954 | 183 | do. | 179 | 841 |
| 175 | do. | 171 | 47944 | 184 | do. | 180 | 856 |
| 175.5 | Junction Fla. | 43 | | 185 | do. | 181 | 831 |
| 176 | U.S. 90 | 172 | 48030 | 186 | do. | 182 | 802 |
| 177 | do. | 173 | 48000 | 187 | do. | 183 | 824 |
| 178 | do. | 174 | 47997 | 188 | do. | 184 | 808 |
| 179 | do. | 175 | 842 | 189 | do. | 185 | 768 |
| 180 | do. | 176 | 883 | 190 | do. | 186 | 757 |
| 181 | do. | 177 | 878 | 190.6 | Junction U.S. 319; Tallahassee | | |
| | | | | 191 | U.S. 90 | 187 | 740 |

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APRIL 1945

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

A RAPID METHOD FOR DETERMINING SURFACE MOISTURE IN COAL



BY

L. D. SCHMIDT AND WM. SEYMOUR

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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By L. D. Schmidt^{2/} and Wm. Seymour^{3/}

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^{1/} The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3811."

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INTRODUCTION.

In the work at the Central Experiment Station of the Bureau of Mines on the problem of controlling the bulk density of the coal charge in byproduct-coke ovens, an acute need developed for a quick, accurate method of measuring the surface-moisture content of crushed coal. As no satisfactory methods for measuring surface-moisture content were available,^{4/} a project was initiated to develop a method. This report covers the findings in the initial phases of this project and describes the tentative method now in use at the Bureau of Mines. The number of requests that have been received for a description of the method at its present state of development indicates the great need of the industry for a reliable measure of surface moisture, and this fact has prompted the authors to prepare this preliminary report of investigations.

As was brought out by Guy,^{5/} the inherent or bed-moisture content of coals ranges from 1 to 46 percent with no surface moisture present. On the other hand, the surface-moisture content of any crushed coal may vary from 0 to 50 percent or more. It is the surface-moisture content rather than either the total or the bed-moisture content that controls primarily such physical properties of crushed coal as bulk density, angle of repose, etc. Furthermore, in such processes as drying or dewatering coal in washeries the real measure of accomplishment is the reduction in surface-moisture content. In this report the total moisture content of wet coal is considered as made up of two components, surface moisture and internal moisture. Presumably the term internal moisture is synonymous with the inherent or bed moisture of coal saturated with moisture but containing no surface water.

^{4/} Guy, T. W., Need for a Standard Method for Determining Surface Moisture in Coal: Trans. Am. Inst. Min. and Met. Eng., vol. 130, Coal Division, 1938, pp. 229-249.

^{5/} Guy, T. W., work cited (footnote 4).

All the present work is based on the idea that the surface moisture of crushed coal can be made to dissolve quickly into solvents such as alcohols, while the internal moisture of the coal remains essentially unaffected. The solvent containing the surface moisture is filtered from the crushed coal and the quantity of surface water determined by measuring the dilution of the solvent.

ACKNOWLEDGMENTS

This investigation was conducted under the direction and with the cooperation of the Coke Production Committee, composed of: A. C. Fieldner, chairman; W. C. Schroeder, secretary; W. T. Brown, consulting engineer; H. M. Chapman, Office of Solid Fuels Administration; H. M. Crossett, Bethlehem Steel Co.; W. A. Haven, Arthur G. McKee Co.; Hjalmar Johnson, Inland Steel Co.; C. D. King, U. S. Steel Corporation; A. R. Powell, Koppers Co.; Samuel Weiss, War Production Board; and H. P. Zeller, Jamison Coal & Coke Co.

W. S. Landers of the Bureau of Mines supervised much of the test work. F. J. Brenenberg conducted many of the tests. H. M. Cooper supervised the chemical analyses and the A.S.T.M. total moistures reported in this paper.

RAPID METHOD FOR DETERMINING SURFACE MOISTURE IN COAL

The following method has been found satisfactory for coking coals and has been in use for more than a year in the research work on bulk-density control by the Bureau of Mines. Little manipulative skill is required with the simple equipment used, and the time required for a determination is about 15 minutes compared to the several hours required for the ordinary total moisture determination in drying ovens (A.S.T.M.).^{6/}

The method is based upon the change in specific gravity of alcohol caused by the absorption of water. The test consists of the extraction of the surface water from coal with a known volume of alcohol and determination of the change in the specific gravity of the alcohol due to absorption of this water. From the data obtained the weight of the surface moisture is calculated.

Apparatus used:

- Buechner funnel (not less than 6-1/4 inches diameter)
- 1,000-ml. suction flask with stopcock at outlet
- Adapter with stopcock
- Vacuum pump or aspirator
- 250-ml. cylinder
- Hydrometers, total range, 0.7800 to 0.880; subdivisions, 0.001 maximum.

^{6/} American Society for Testing Materials, Sampling and Analysis of Coal and Coke (A.S.T.M. Designation D271-42, A.S.A. No. K18-1942): Am. Soc. Test. Mat. Standards, 1942, pt. III, Nonmetallic Materials.

Thermometer, 10° to 35° C., subdivisions 1°
 500-ml. volumetric flask.
 Balances, 2 kg. capacity; accurate to 1 gram
 Filter papers for Buechner funnel
 Vacuum gauge or manometer desirable
 Necessary suction tubing
 Stand for apparatus
 Sample jars, about 2-liter capacity, with airtight covers (2-quart fruit jars are satisfactory).

Chemical used:

Ethyl alcohol or ethyl alcohol denatured with wood alcohol.

The set-up of the filtering apparatus is shown in figure 1. Enough sample to about half fill the sample jar is taken, usually about 500 to 600 grams. These samples may be obtained at a mine, washery, plant, or yard, closed tightly to avoid loss of moisture, and transported to a convenient place for analysis. The extraction is performed in the sample jar in order to include any free water that may be on the lid or inside the jar. The net weight of the sample is determined from the gross and tare weights of the sample jar. The specific gravity and temperature of the alcohol are determined and exactly 500 ml. of alcohol is measured in the volumetric flask. A filter paper of the correct size is placed in the Buechner funnel and weighted down with a chain or ring. The funnel and suction flask should be dry or may be washed with the alcohol before the specific gravity and temperature are taken. Close stopcock A, open stopcock B, and evacuate flask. The 500 cc. of alcohol is then added to the sample of coal in the jar, the cover replaced, the mixture agitated slightly and pressure released, then allowed to stand for exactly 5 minutes with frequent and thorough shaking. Decant the contents of the jar into the Buechner funnel; close stopcock B, and draw off the alcohol from the coal by opening stopcock A. When the pressure is equalized shut stopcock A, disconnect flask from Buechner funnel, shake well, and pour enough of the filtrate into the 250-ml. cylinder to take specific gravity and temperature.

Specific-gravity readings should be estimated to the fourth decimal place and temperatures to nearest 0.1° C. The specific gravity is corrected to 25° C. (or any convenient temperature). The temperature correction for specific gravity is 0.0008 per degree C. deviation from the base in the range ordinarily used in these tests. The percentages of alcohol before and after treatment are taken from a graph prepared from results obtained by the addition of known weights of water to 500 m. of the alcohol to be used, or prepared from data in the International Critical Tables.^{7/}

The water absorbed by the alcohol is calculated as follows:

$$\text{Water from coal, grams} = V_i d_i \left[\frac{A_i}{A_f} - 1 \right];$$

V_i = initial volume of alcohol, in ml.

^{7/} International Critical Tables, vol. 3, 1928, pp. 116-117.

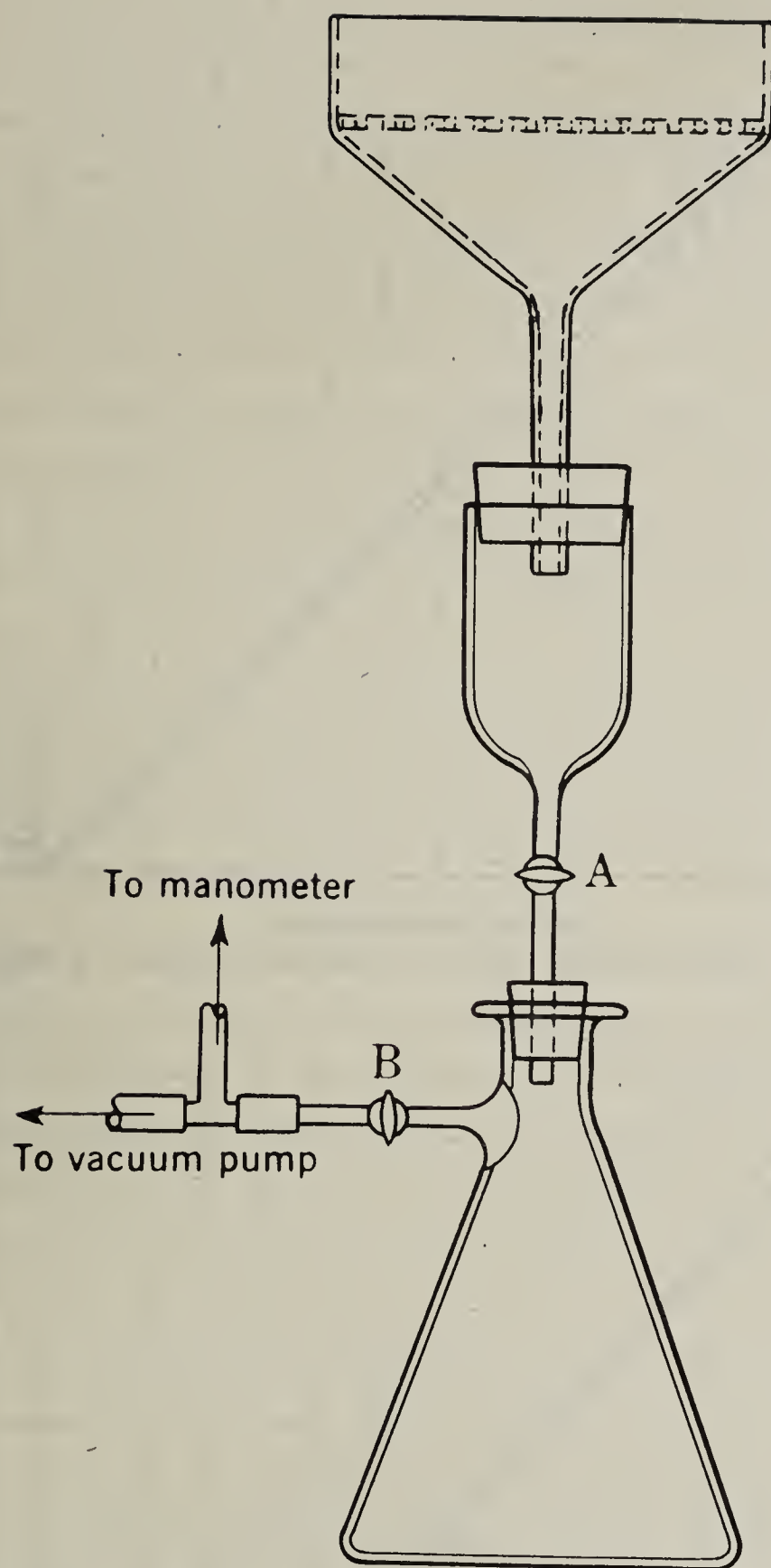


FIGURE 1.- Apparatus for determination of moisture in coal.



Fig. 1. Apparatus for the separation of a mixture.

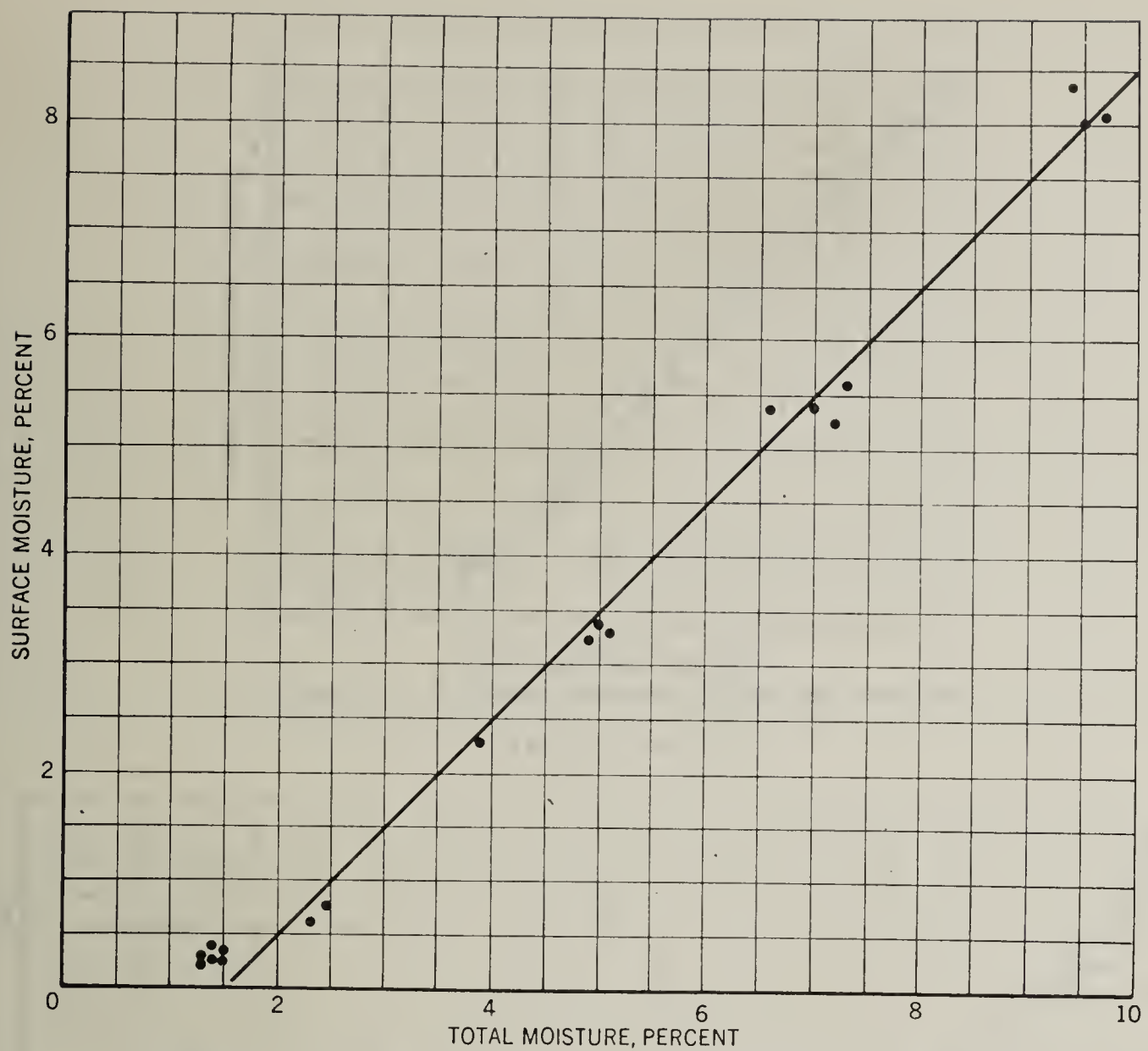


FIGURE 2.- Relation between total and surface moisture, coal A.

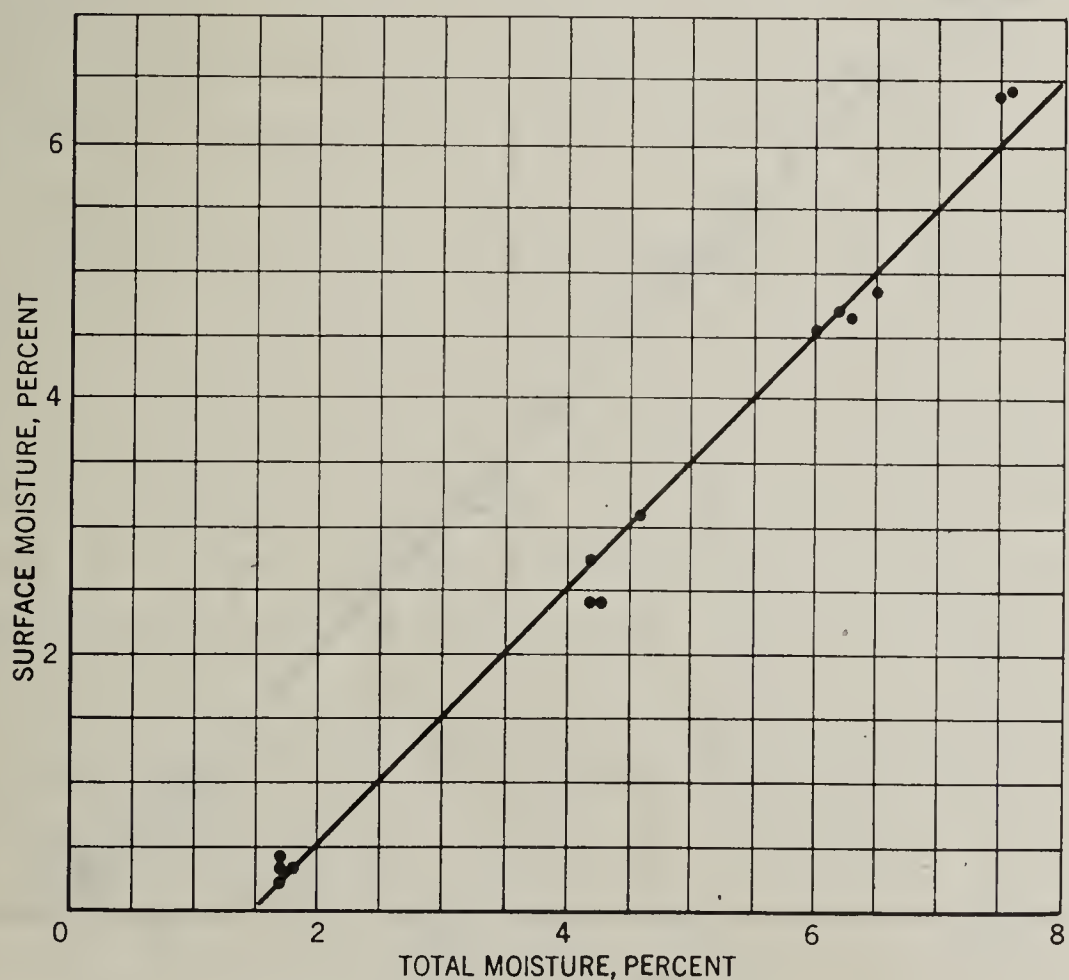


FIGURE 3.- Relation between total and surface moisture, coal B.



Figure 1: A line graph showing a linear relationship between two variables.



Figure 2: A line graph showing a linear relationship between two variables.

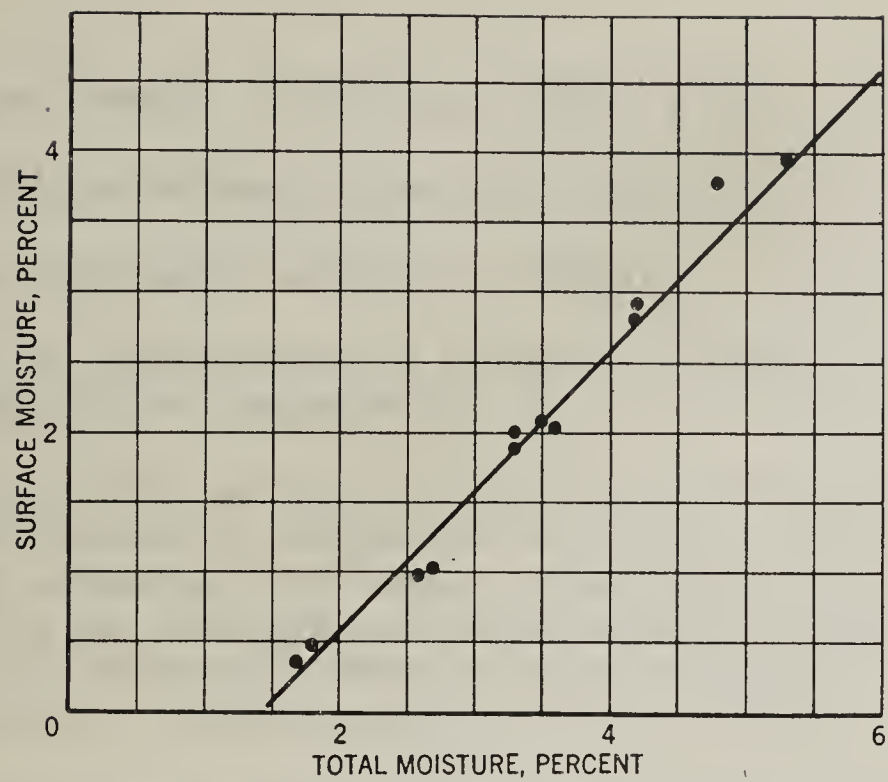


FIGURE 4.- Relation between total and surface moisture, coal C.

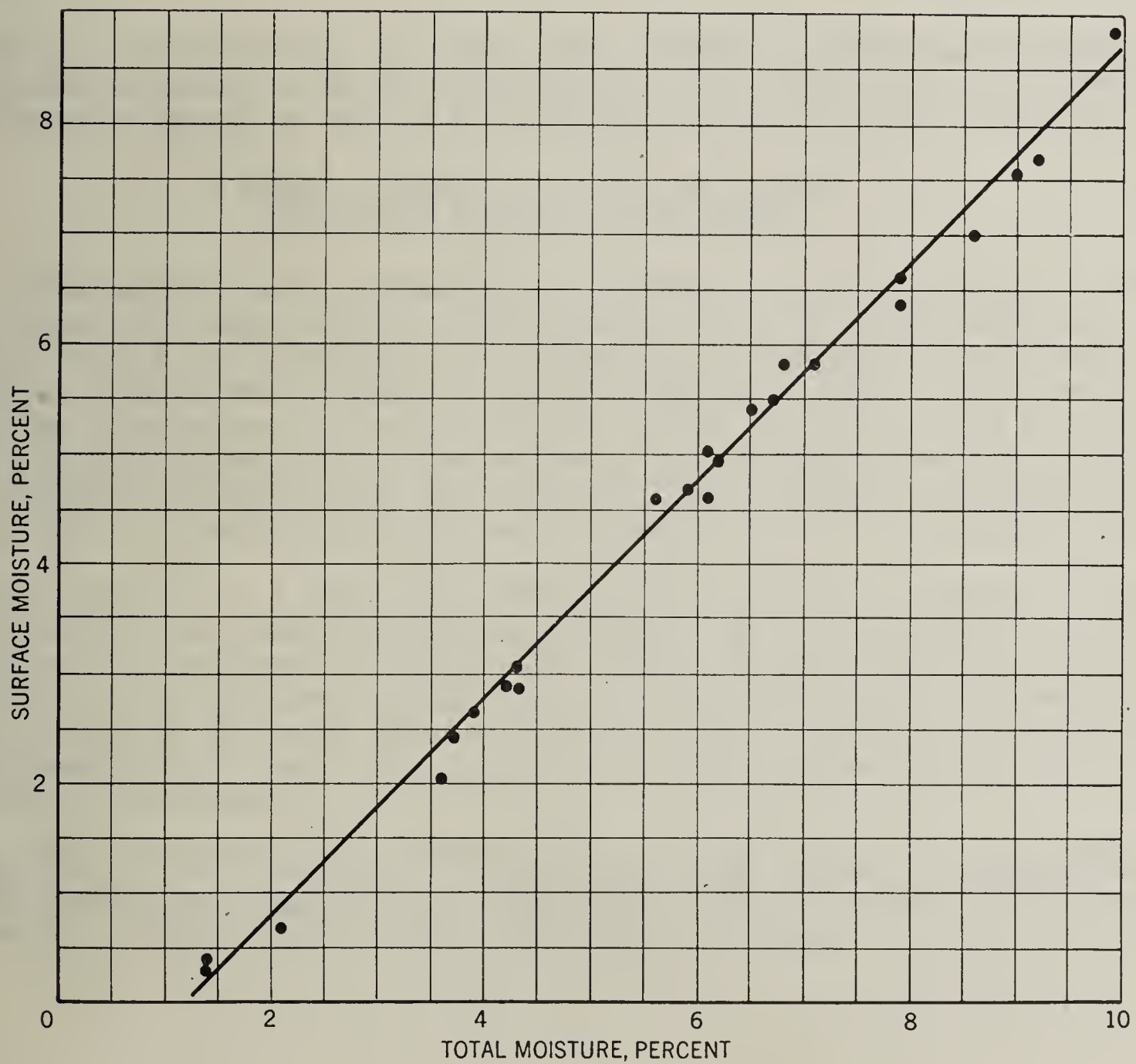


FIGURE 5.- Relation between total and surface moisture, coal D.



Figure 1. Temperature vs. Time (1998)



Figure 2. Temperature vs. Time (1999)

d_i = initial density of alcohol, grams per ml.

A_i = initial percentage alcohol by weight.

A_f = final percentage alcohol by weight.

The alcohol can be reused until it contains at least 30 percent water. The lowest limit has not been determined.

Tests indicate that the particle size of the coal is not important as long as there are not excessive amounts of very fine coal. Although some internal moisture is extracted from samples ground in a ball mill to minus 60-mesh as prepared in the standard laboratory method, usually the percentage of such material in the ordinary commercial sizes of coal is so small that the error due to extraction of internal moisture is negligible.

The method has been thoroughly checked for use on the high-grade, low-internal-moisture coking coals of the east and found to be reliable on these coals.

Tests on subbituminous coal with high inherent moisture indicate that the internal moisture is slowly extracted and that extrapolation or a method of calculation should be applied to determine surface moisture accurately.

RESULTS OBTAINED ON COALS AS CRUSHED FOR USE IN BYPRODUCT-COKE OVENS

In the work of developing methods of control of the bulk density of the coal charged into byproduct-coke ovens, large samples of the crushed coal actually used at four commercial coke plants were obtained.^{8/} Each large sample was divided into a number of smaller samples or lots, and different quantities of water were added to each lot. After suitable mixing a 1-quart sample was taken from each lot for determination of surface and total moisture. Total moisture was obtained by the regular A.S.T.M. method, utilizing a drying oven at 105° C. Surface moistures were determined by the method given above.

In figures 2, 3, 4 and 5 the surface moisture of these samples is shown plotted against the total moisture as determined by oven drying. It will be noted that the experimental results fall closely along straight lines. The deviations of the individual points from the straight line include sampling errors, errors in the total moisture determination (A.S.T.M.), and errors in the surface-moisture test. In general, the results indicate very satisfactory precision of measurement.

^{8/} Landers, W. S., Schmidt, L. D., and Seymour, Wm., Control of Bulk Densities in Coke Ovens: Studies on the Coal Used at Three Byproduct Coke Plants: Bureau of Mines Report of Investigations, in press.

Table 1 shows the proximate and sieve analyses of the four large coal samples used in these tests. Each sample is a blend of high- and low-volatile coals. It will be noted that the sieve analyses show a considerable range in the fineness of crushing in these four samples.

In figures 2 to 5 it will be noted that for these four coking-coal mixes when the surface moisture is zero the total moisture ranges only from 1.3 to 1.5 percent. This shows that these coals have virtually the same internal moisture content. However, as was mentioned before, other coals show internal moisture contents as high as 46 percent. None of the coals of high internal moisture content can be classed as coking coals.

RATE OF EXTRACTION OF INTERNAL MOISTURE

If very finely ground coal is tested by the above method the total moisture content of the coal is obtained; that is, if the particle size is extremely small the alcohol extracts both surface and internal moisture in the 5 minutes contact time allowed. Even with larger pieces, if the alcohol is left in contact with the coal long enough the internal moisture will be extracted. To get a clear-cut distinction between surface moisture and internal moisture it is necessary to know something about the rate of extraction of internal moisture. Because the internal-moisture content of coking coals is so low it proved difficult to obtain precise measurements on the rate of extraction of these small quantities of water. Consequently a series of experiments were run using a coal of subbituminous B rank^{9/} and having a high content of internal moisture. Table 2 shows the source and analysis of this coal, which consisted of 1-1/4-inch float coal on 1.35 specific gravity. This coal had been stage-crushed to pass a 1/4-inch sieve, and the resulting sieve analysis is shown also in table 2. The method of determining surface moisture used in this series of tests was modified so that instead of allowing the ethyl alcohol to stand for 5 minutes on the coal with frequent agitation, it was shaken once and decanted immediately, the temperature and specific gravity of the filtrate taken, and then the filtrate returned to the coal in the Buechner funnel. This process was repeated several times, noting the total time interval that the coal was in contact with the alcohol. When eastern coals were subjected to this procedure the specific gravity of the filtrate remained virtually constant after two or three cycles. A cycle required about 3 minutes. With the subbituminous coal, the specific gravity of the filtrate did not remain constant; it continued to increase but at a decreasing rate, even after seven treatments (about 21 minutes). This indicates that the alcohol was extracting the internal moisture. The results are shown in figure 6. It will be noted that when this coal was extracted for 2 minutes 1.3 percent of internal moisture was extracted, whereas 20 minutes exposure to alcohol resulted in the extraction of 4.5 percent moisture.

^{9/} American Society for Testing Materials, Standard Specifications for Classification of Coals by Rank (A.S.T.M. Designation D388-38, A.S.A. No. M20.1-1938): Am. Soc. Test. Mat. Standards, 1942, pt. III, Nonmetallic Materials, pp. 1-6.

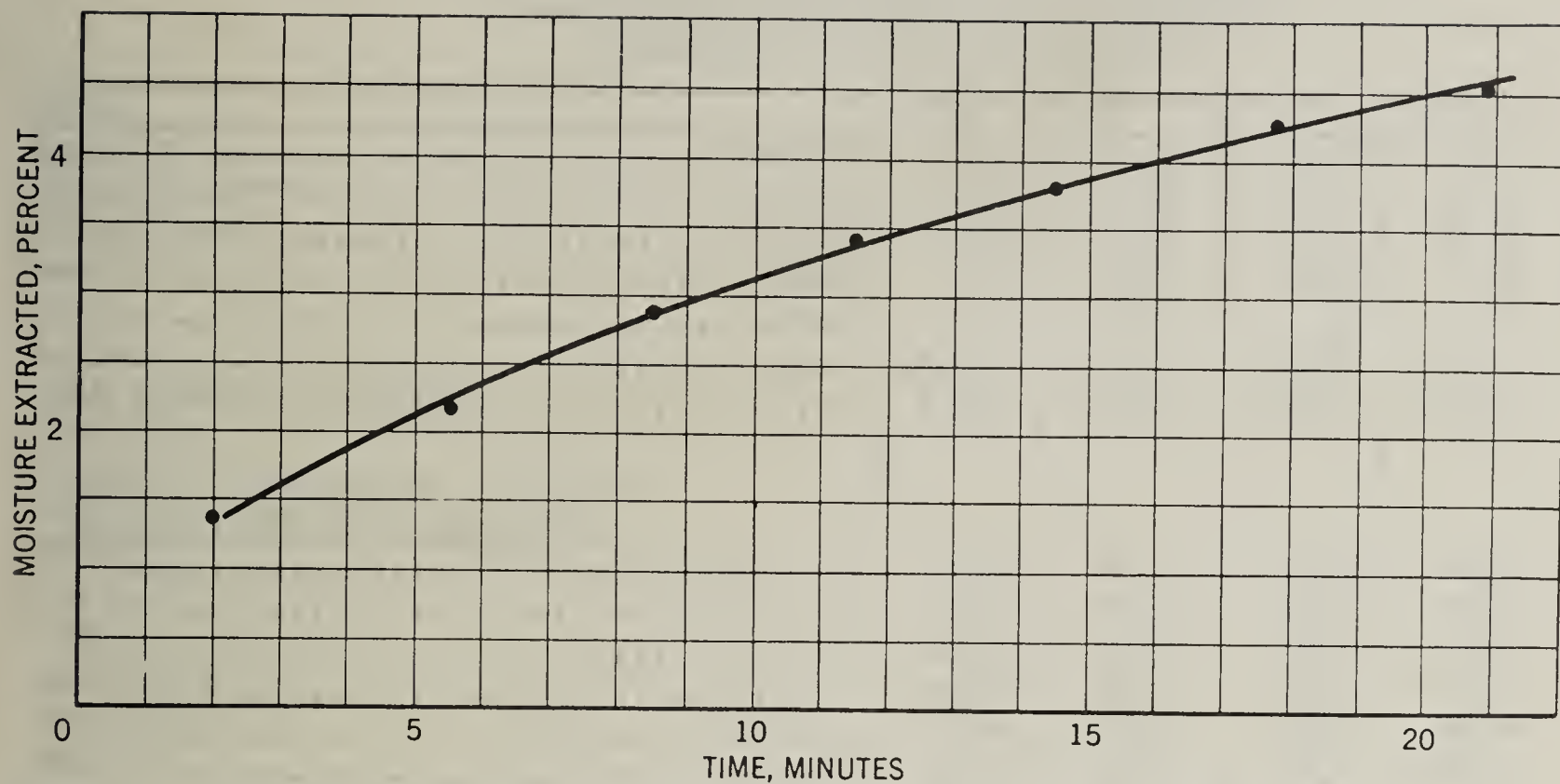


FIGURE 6.- Moisture extracted from air-dried, 0 x 1/4-inch Moore mine coal.

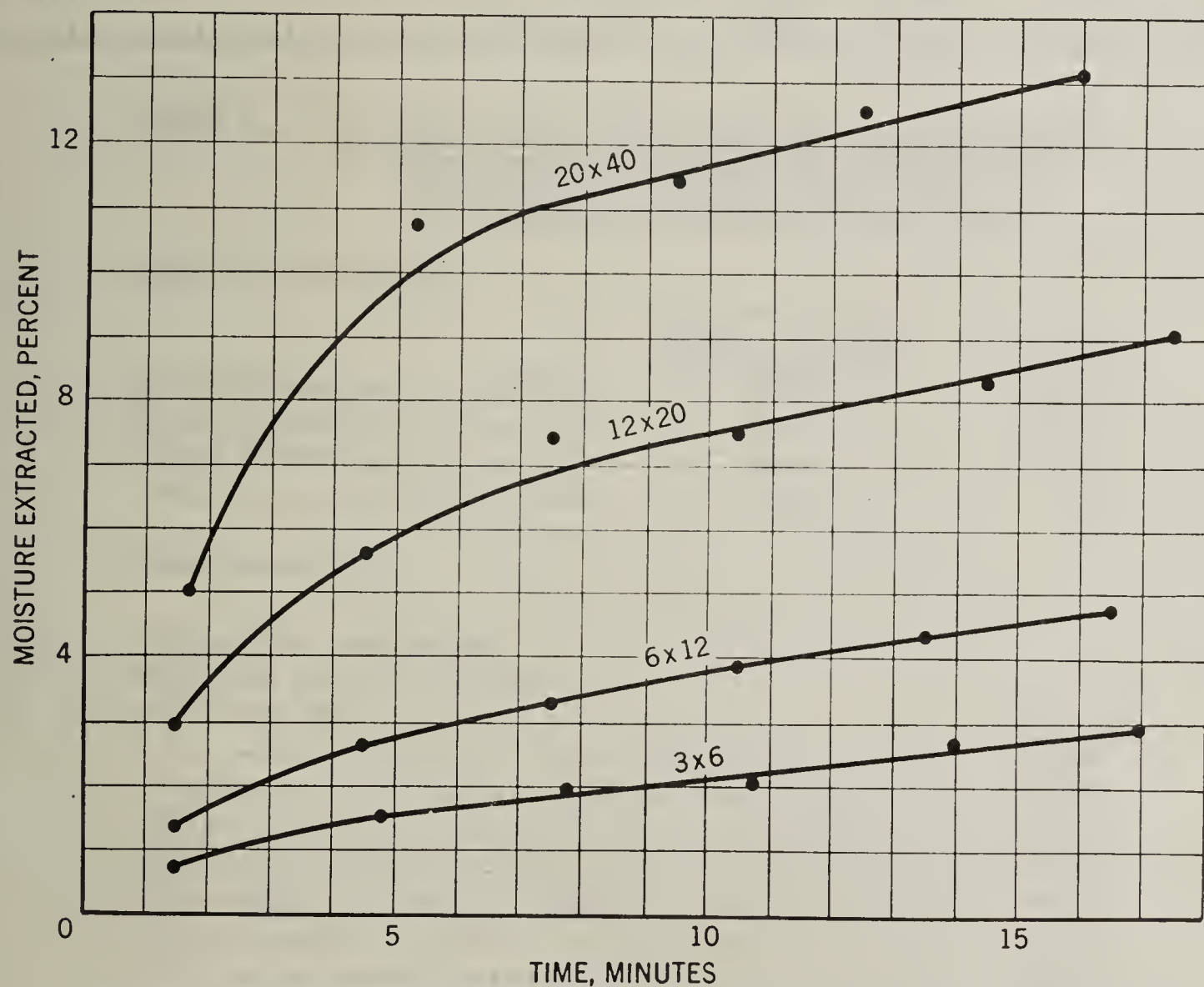


FIGURE 7.- Moisture extracted from various sieve sizes of air-dried, Moore mine coal.



Figure 1: A graph showing the relationship between two variables, with the curve representing a decreasing trend.



Figure 2: A graph showing the relationship between two variables, with three curves representing different rates of decrease.

TABLE 1. - Proximate and sieve analyses of samples of crushed coal obtained by byproduct-coke plants (as-received basis)

| Coal: | A | B | C | D |
|--|--------|--------|--------|--------|
| MoisturePercent | 2.0 | 6.0 | 1.9 | 1.7 |
| Volatile matterdo. | 29.0 | 31.8 | 34.1 | 22.8 |
| Fixed carbondo. | 61.6 | 55.5 | 57.4 | 66.2 |
| Ashdo. | 7.4 | 6.7 | 6.6 | 9.3 |
| Sulfurdo. | .6 | 1.2 | .9 | .7 |
| B.t.u. | 13,850 | 13,270 | 13,880 | 13,720 |
| Real specific gravity | 1.353 | 1.344 | 1.335 | 1.372 |
| Cumulative percentage retained on U. S. Standard Sieve No. | | | | |
| 4 | 6.9 | 22.1 | 10.3 | 12.4 |
| 6 | 13.0 | 31.5 | 18.2 | 20.1 |
| 8 | 20.9 | 40.8 | 25.8 | 26.8 |
| 16 | 40.9 | 59.0 | 46.3 | 45.2 |
| 40 | 68.4 | 79.5 | 74.0 | 70.9 |
| 80 | 83.6 | 89.5 | 88.4 | 85.0 |
| 140 | 89.6 | 93.0 | 93.5 | 90.7 |
| 200 | 92.8 | 94.9 | 95.5 | 94.0 |
| Pan | 100.0 | 100.0 | 100.0 | 100.0 |

TABLE 2. - Proximate and sieve analysis of washed and stage-crushed Coalmont-bed coal from Moore mine, Jackson County, Colo.

Proximate analysis:

| | As received at Bureau of Mines | Air-dried |
|-------------------------|-----------------------------------|-----------|
| Moisture..... percent | 16.2 | 15.1 |
| Volatile matter.....do. | 34.0 | 34.5 |
| Fixed carbon.....do. | 44.1 | 44.6 |
| Ash.....do. | 5.7 | 5.8 |

Sieve analysis:

| Cumulative percentage retained on U. S. Standard Sieve No. | Percent |
|--|---------|
| 4 | 25.4 |
| 8 | 72.8 |
| 16 | 91.1 |
| 40 | 97.8 |
| 80 | 99.3 |
| 140 | 99.7 |
| 200 | 99.9 |
| Pan | 100.0 |

A second series of tests was made on screen sizes of air-dried coal from the Moore mine. Results are shown in figure 7. It will be noted that the initial rates of extractions of internal moisture were much higher for the fine sizes.

A third series of tests was made on this air-dried, 0 x 1/4-inch coal, to which various percentages of water had been added. The results are shown in figure 8. The percentage of added water based on weight of air-dried coal is shown on each curve.

A fourth series of tests was made on separate sieve fractions of air-dried Moore mine coal to which various percentages of water had been added. The results are shown in figure 9. These tests indicate that the surface moisture is removed very rapidly, within 4 or 5 minutes in most cases, and then there is a gradual absorption of the inherent moisture at a much lower rate, which is fairly uniform for at least 10 or 15 minutes. This uniform rate of absorption of the internal moisture appears to be independent of the percentage of moisture added. The results show that some of the internal moisture had evaporated in air drying and that part of the added water was resorbed as internal moisture.

USE OF METHYL ALCOHOL IN DETERMINING SURFACE MOISTURE

All the tests previously described were made using denatured ethyl alcohol. The use of methyl alcohol has some favorable points and some unfavorable. At the present time methyl alcohol may prove to be more easily available. It can be obtained in a very pure state and it dissolves water very rapidly. In some cases the latter quality may prove to be a disadvantage in that the series of tests to be described show that methyl alcohol extracts internal moisture from the coal at a higher rate than does ethyl alcohol.

A series of tests was made on a sample of coal from the Warden mine in the Pittsburgh bed. This coal had been stage-crushed to pass a 1/4-inch screen. Table 3 shows the proximate and sieve analysis of this coal. Ten lots of this coal, as received, were put into ten 2-quart fruit jars, various amounts of water added, and the jars closed tightly and allowed to stand for 40 hours. The samples were then subjected to the regular procedure for determining surface moisture, using methyl instead of ethyl alcohol. The results of these tests are given in table 4 and in figure 10. The results show that in all cases more water was extracted by the methyl alcohol than had been added to the coal. This shows that the methyl alcohol extracts some internal moisture from the coal.

Another series of tests was made on this same coal to compare directly the effect of changing from ethyl to methyl alcohol. Six samples of the 0 x 1/4-inch coal (as received) were placed in six 2-quart fruit jars. Fifteen grams of water were added to each sample. Three samples were tested with methyl alcohol and three with the regular denatured alcohol. In the results shown in table 5 it will be noted that the methyl alcohol extracted nearly 0.5 percent more water than did the ethyl alcohol.

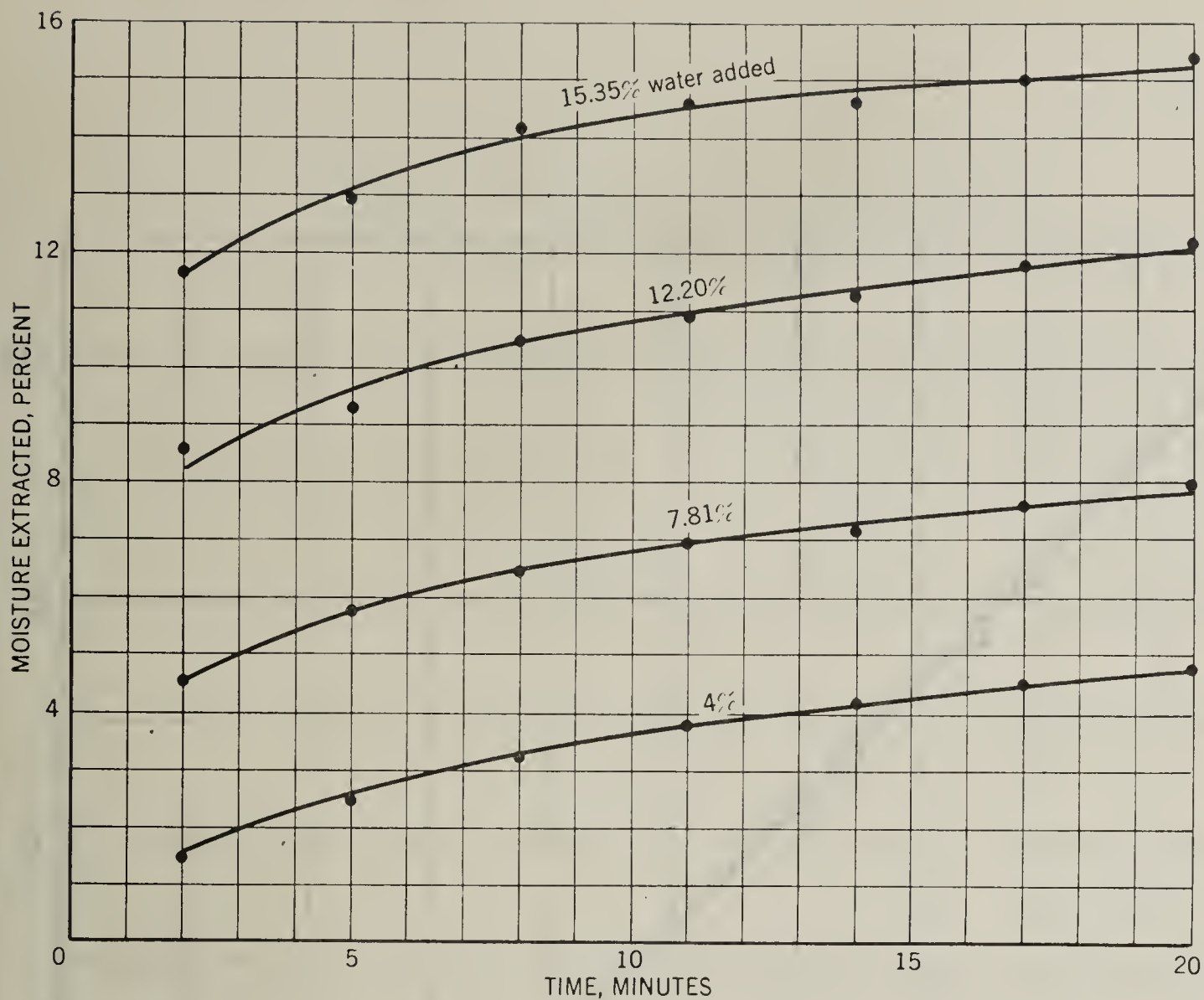


FIGURE 8.- Moisture extracted from 0 x 1/4-inch, air-dried, Moore mine coal to which water had been added.

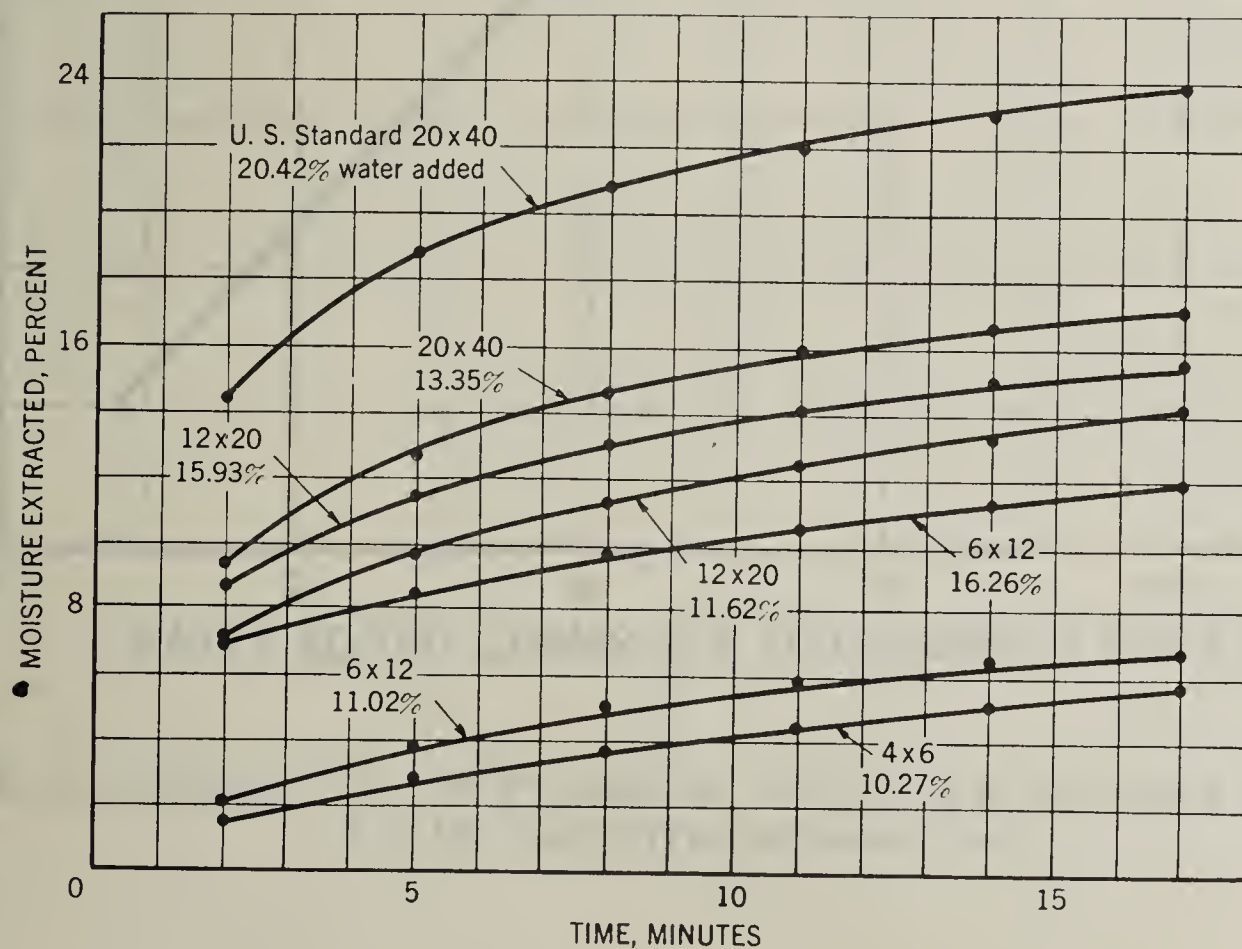
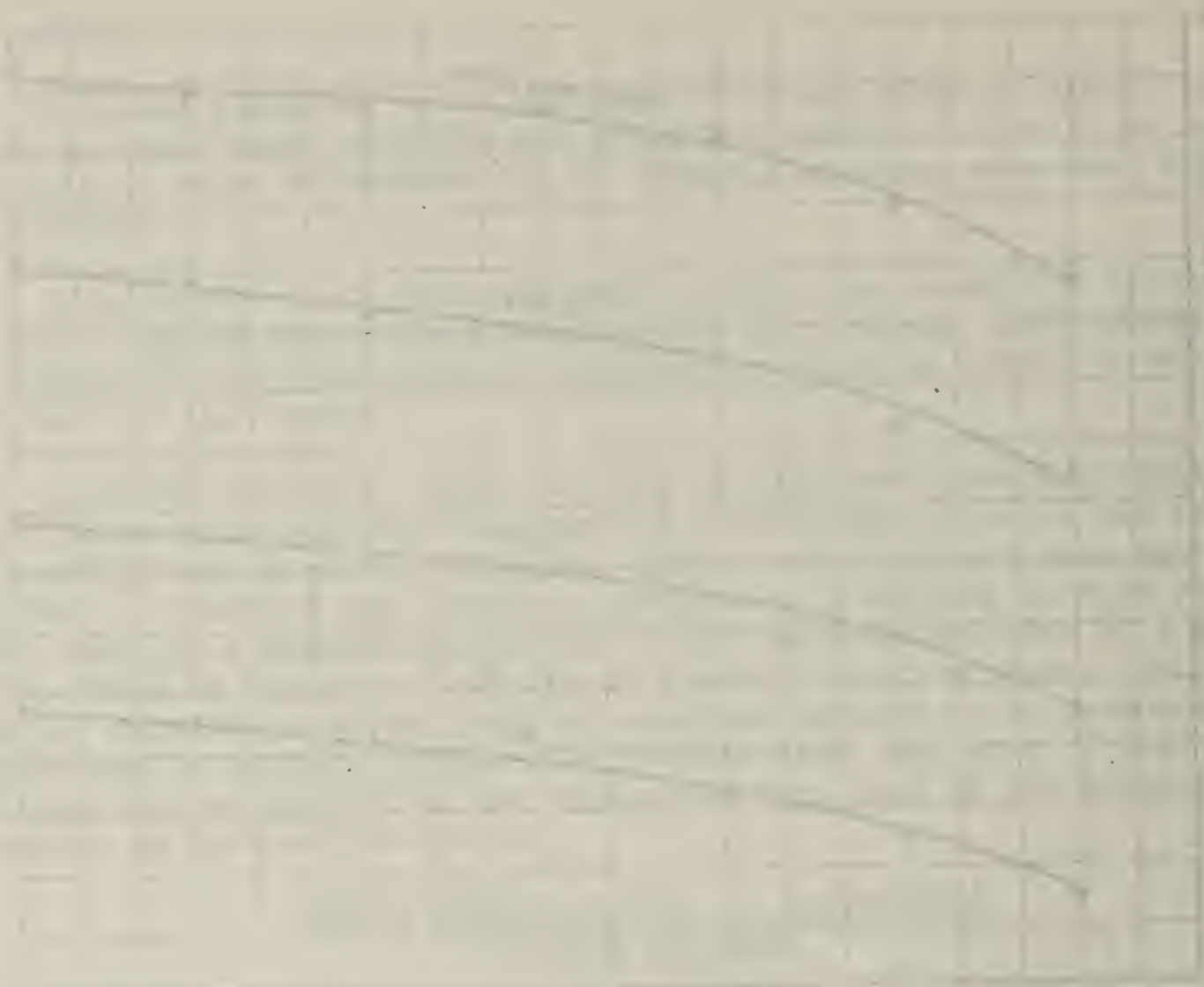


FIGURE 9.- Moisture extracted from air-dried, Moore mine coal in various sieve sizes to which water had been added.



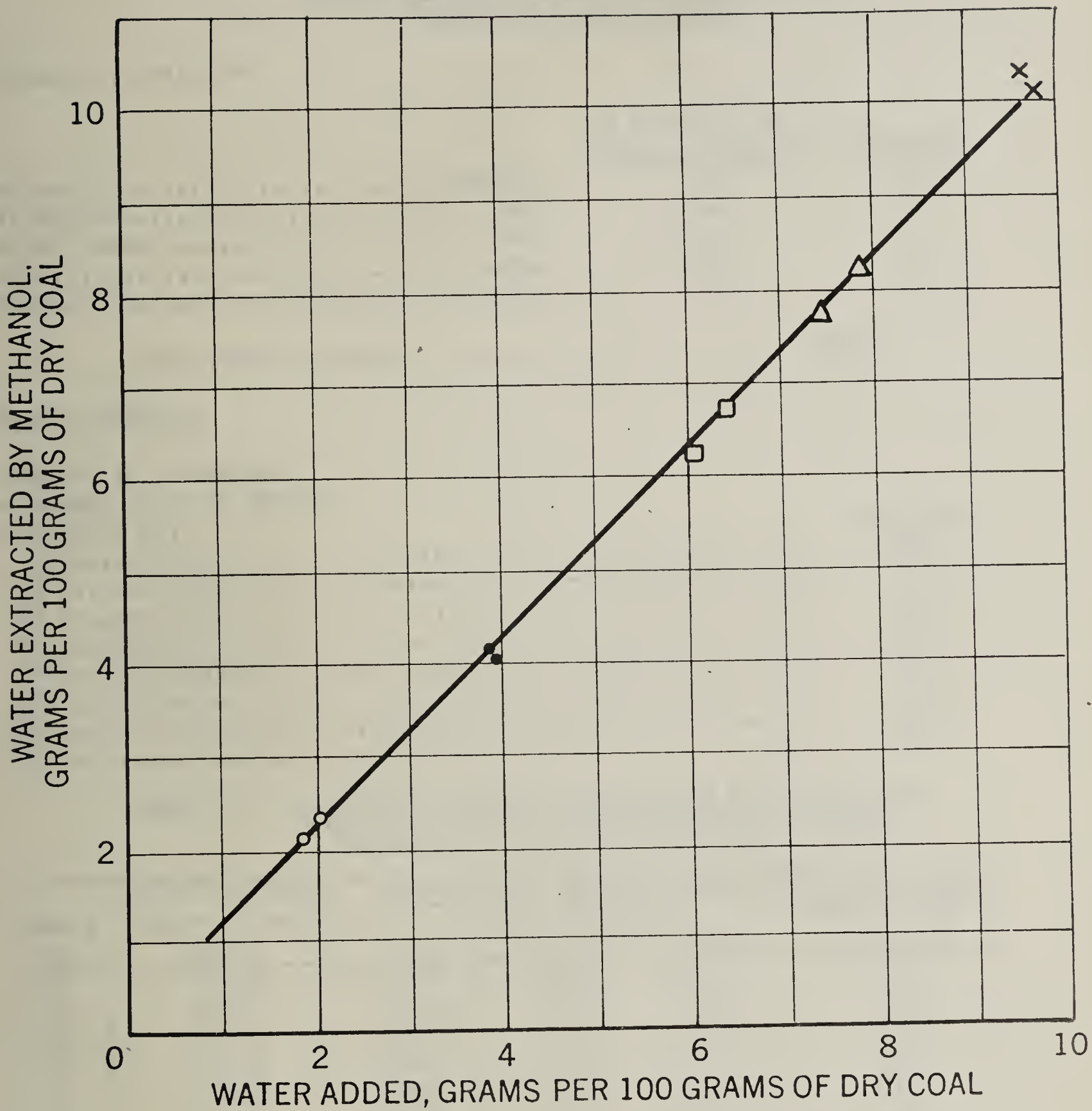


FIGURE 10.- Relation of water added to coal to that extracted by methanol, 0 x 1/4-inch Pittsburgh-bed coal.

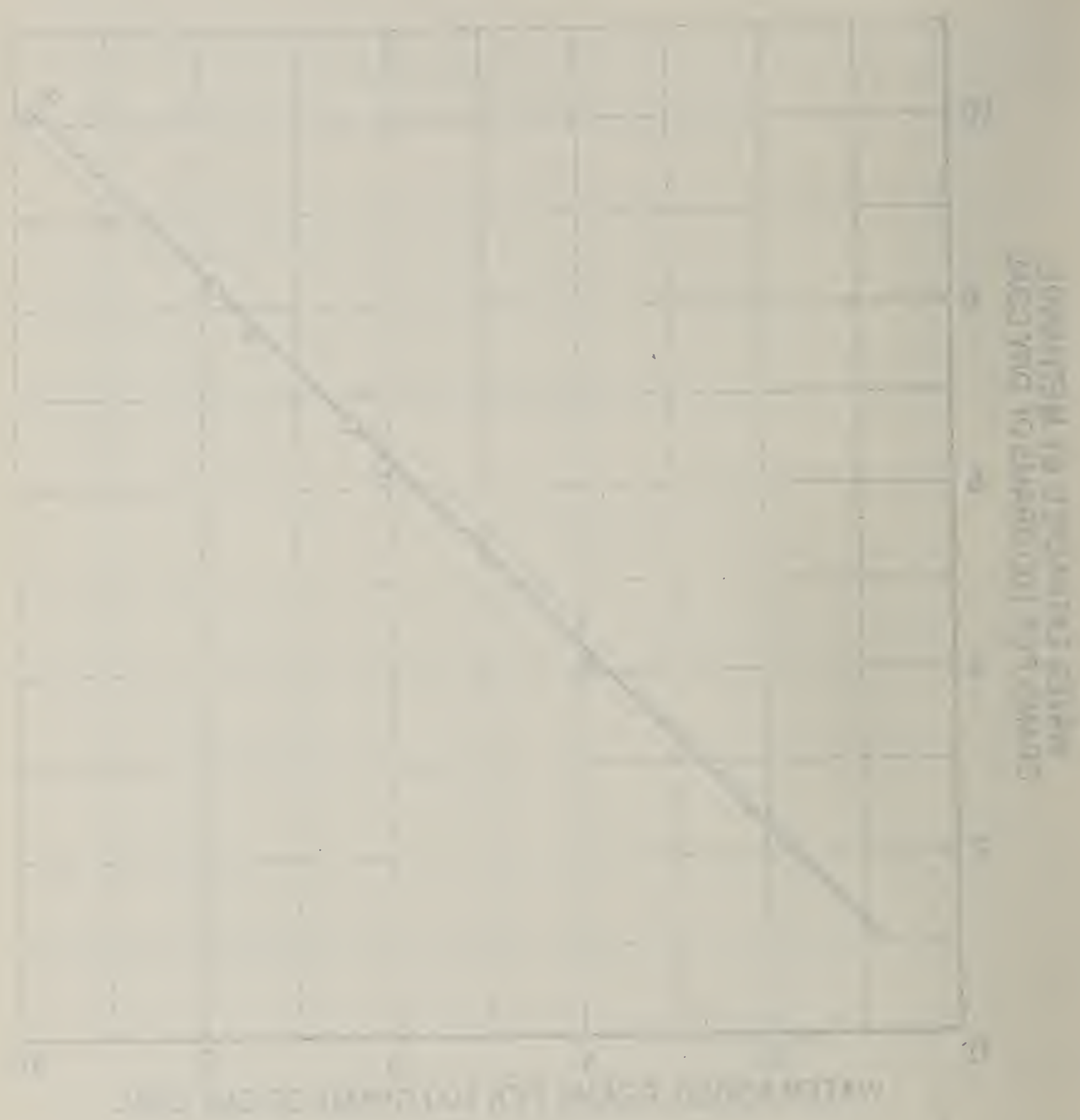


Fig. 1. Dependence of the refractive index on the concentration of the solution.

TABLE 3. - Proximate and sieve analysis of Pittsburgh bed coal from Warden mine, stage-crushed to pass a 1/4-inch screen

Proximate analysis:

| | As received by Bureau of Mines | Air-dried |
|-----------------------|-----------------------------------|-----------|
| Moisturepercent | 1.8 | 1.3 |
| Volatiledo. | 37.2 | 37.4 |
| Fixed carbondo. | 56.9 | 57.1 |
| Ashdo. | 4.1 | 4.2 |
| Sulfur.....do. | .8 | .8 |

True specific gravity 1.311

Sieve analysis:

Cumulative percentage
retained on U. S. Stand-
ard Sieve No.

| | Percent |
|-----------------|---------|
| 4 30.6 | |
| 8 67.6 | |
| 16 83.6 | |
| 40 94.2 | |
| 80 98.1 | |
| 140 99.2 | |
| 200 99.8 | |
| Pan 100.0 | |

TABLE 4. - Extraction of water from wetted Pittsburgh-bed coal (0 x 1/4-inch), using methyl alcohol

| Sample No. | Weight of sample (dry-coal basis), grams | Water added, grams | | Water extracted, grams | |
|---------------|--|--------------------|---------------------------|------------------------|---------------------------|
| | | Total | Per 100 grams dry coal | Total | Per 100 grams dry coal |
| 17 | 687.3 | 13.0 | 1.89 | 14.5 | 2.11 |
| 18 | 638.5 | 13.0 | 2.04 | 14.9 | 2.33 |
| 19 | 661.5 | 26.0 | 3.93 | 26.9 | 4.07 |
| 20 | 667.3 | 26.0 | 3.90 | 27.5 | 4.12 |
| 21 | 606.8 | 39.0 | 6.43 | 40.8 | 6.72 |
| 22 | 640.0 | 39.0 | 6.09 | 40.2 | 6.28 |
| 23 | 659.6 | 52.0 | 7.88 | 54.2 | 8.22 |
| 24 | 699.8 | 52.0 | 7.43 | 54.2 | 7.75 |
| 25 | 667.0 | 65.0 | 9.75 | 67.8 | 10.16 |
| 26 | 676.3 | 65.0 | 9.61 | 69.9 | 10.34 |

TABLE 5. - Direct comparison of extraction of water from wetted coal by methyl and ethyl alcohol

| Alcohol used | Weight of sample grams | Water added | | Water extracted | | Differ- ence |
|------------------|---------------------------|-------------|---------|-----------------|---------|-----------------|
| | | Grams | Percent | Grams | Percent | |
| DENATURED ETHYL: | | | | | | |
| | 606.1 | 15.0 | 2.47 | 12.80 | 2.11 | -0.36 |
| | 558.9 | 15.0 | 2.68 | 14.41 | 2.58 | -.10 |
| | 596.0 | 15.0 | 2.52 | 14.54 | 2.44 | -.08 |
| Average | 587.0 | 15.0 | 2.56 | 13.92 | 2.38 | -.18 |
| METHYL: | | | | | | |
| | 600.8 | 15.0 | 2.50 | 16.78 | 2.79 | +0.29 |
| | 593.2 | 15.0 | 2.53 | 16.24 | 2.74 | +.21 |
| | 566.8 | 15.0 | 2.65 | 17.10 | 3.02 | +.37 |
| Average | 586.9 | 15.0 | 2.56 | 16.71 | 2.85 | +.29 |

A number of tests were made to learn how finely coal must be crushed to have methyl alcohol extract all of the internal moisture in a 5-minute period of exposure. Five samples of air-dried coals from various sources and selected at random from those prepared by the Coal Analysis Laboratory for analysis were tested. These samples had been air-dried and then pulverized in a ball mill to pass a No. 60 sieve. Sieve analyses on the samples showed that about 35 to 40 percent of the coal would pass a No. 200 sieve. The results of the extraction with methyl alcohol are shown in table 6. It is apparent that, under the conditions of test, methyl alcohol extracts all the moisture from these coals crushed to pass a No. 60 sieve.

TABLE 6. - Comparison of A. S. T. M. oven moistures with moisture by extraction with methyl alcohol

| Sample No. | Moisture, percent | |
|------------|-------------------|------------------|
| | Methyl alcohol | A. S. T. M. oven |
| 31 | 1.91 | 1.25 |
| 32 | 8.49 | 6.77 |
| 33 | 2.45 | 1.11 |
| 34 | 18.97 | 18.42 |
| 35 | 2.01 | 1.29 |

Similar tests were made on three samples selected at random from Coal Analysis Laboratory samples crushed to pass a No. 60 sieve and extracted with ethyl alcohol. The results in table 7 show that under the conditions of test the ethyl alcohol does not remove all the internal moisture from coal ground to pass a No. 60 sieve.

TABLE 7. - Comparison of A. S. T. M. oven moisture with moisture obtained by extraction with ethyl alcohol

| Sample No. | Moisture, percent | |
|------------|-------------------|------------------|
| | Ethyl Alcohol | A. S. T. M. oven |
| 4707 | 0.36 | 1.25 |
| 4708 | 1.00 | 1.70 |
| 4709 | 1.14 | 1.75 |

The ordinary commercial sizes of coal and, for that matter, even crushed coal as used to charge byproduct-coke ovens contain only small percentages of coal that will pass a No. 60 sieve. Consequently the amount of extraction of internal moisture from these sizes when ethyl alcohol is used is very small. As a result, denatured ethyl alcohol can be used to measure the surface moisture content of coking coals. In all probability it can also be used for the ordinary commercial sizes of most noncoking coals without any great error resulting from extraction of internal moisture in the 5-minute period allowed for these tests.

Further research is being conducted to enable a finer distinction to be drawn between surface and internal moisture. However, the method as it stands should prove precise enough for most practical applications.

SUMMARY AND CONCLUSIONS

A rapid method has been developed for measuring the surface moisture content of coal. Although development work is still proceeding to prove the method and ascertain its limitations more precisely, the method as described should be directly applicable to many problems in industry.

There are indications that the procedure can be used for a rapid, precise determination of total moisture content of coal if the latter is crushed to pass a No. 60 sieve and is extracted with methyl alcohol. The higher alcohols, such as ethyl and isopropyl, are better adapted to differentiating between surface and internal moisture in coal. Undoubtedly the same procedure could be used with other solvents.

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

EQUILIBRIUM IN THE REDUCTION OF FERROUS CHROMITE
BY HYDROGEN AND ENERGY REQUIREMENTS IN THE
SELECTIVE REDUCTION OF IRON IN CHROMITE



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BY

F. S. BOERICKE AND W. M. BANGERT

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REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

EQUILIBRIUM IN THE REDUCTION OF FERROUS CHROMITE BY HYDROGEN
AND ENERGY REQUIREMENTS IN THE SELECTIVE REDUCTION
OF IRON IN CHROMITE^{1/}

By F. S. Boericke^{2/} and W. M. Bangert^{3/}

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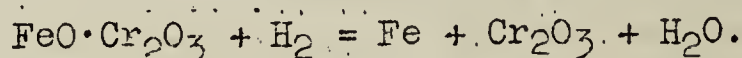
INTRODUCTION

Determination of the thermodynamic properties of metallurgically important compounds of chromium has been one of the activities of the Pacific Experiment Station of the Bureau of Mines. Earlier reports have dealt with the entropies^{4/ 5/} of chromium, chromic oxide, and chromous and chromic chlorides, with the thermodynamic properties of the chlorides of chromium,^{6/}

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- ^{1/} The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3813."
- ^{2/} Metallurgist, Pacific Experiment Station, Bureau of Mines.
- ^{3/} Formerly Metallurgist, Pacific Experiment Station, Bureau of Mines.
- ^{4/} Anderson, C. T., The Heat Capacities of Chromium, Chromic Oxide, Chromous Chloride, and Chromic Chloride at Low Temperatures: Jour. Am. Chem. Soc., vol. 59, 1937, p. 488.
- ^{5/} Kelley, K. K., Contributions to the Data on Theoretical Metallurgy. IX. The Entropies of Inorganic Substances. Revision (1940) of Data and Methods of Calculation: Bureau of Mines Bull. 434, 1941, 115 pp.
- ^{6/} Doerner, H. A., Chemistry of the Anhydrous Chlorides of Chromium. A Thermodynamic Investigation: Bureau of Mines Tech. Paper 577, 1937, 51 pp.

and with the thermodynamic properties of the carbides and oxide of chromium.^{7/} Evaluation of the thermodynamic properties of chromite, $\text{FeO} \cdot \text{Cr}_2\text{O}_3$, is desirable, as this material in impure form constitutes the only natural source of chromium of any consequence.

Two general methods are available for directly determining heats of formation - (1) measurement of heats of combustion and (2) measurement of heats of solution. Neither of these methods is directly applicable at present to ferrous chromite, which accounts for the lack of previous data. Combustion of a stoichiometrical mixture of iron and chromium under conditions prevailing in a calorimetric bomb yields a mixture of iron and chromium oxides rather than chromite. None of the usual calorimetric solution media dissolve chromite at temperatures low enough for solution calorimetry. Sulfuric acid and an oxidizing agent, such as MnO_2 or CrO_3 , are known to dissolve chromite, but the possible calorimetric use of this medium would require long preliminary investigation. Consequently, recourse must be taken to some indirect method. At the start of the present work, the most promising method appeared to be the determination of equilibria in the selective reduction of the iron in chromite by hydrogen,



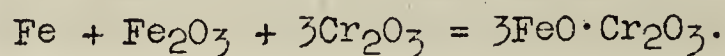
Subsequent trials showed the method to yield adequate results.

This report deals with the preparation of substantially pure ferrous chromite, the apparatus and method for studying equilibria in the selective hydrogen-reduction reaction, the derivation of the heat and free energy of formation of ferrous chromite from the equilibrium data, and some applications of the thermodynamic values to selective reduction of chromite by other reducing agents, particularly solid carbon and methane.

MATERIALS AND METHODS

Preparation of Ferrous Chromite

Ferrous chromite was made by the reaction



A powdered mixture of the three ingredients was heated first in a sealed iron tube at $1,100^\circ$ to $1,300^\circ$ C. for 5 days. The iron tube was surrounded by a porcelain tube, and the annular space between them was flushed with helium to prevent oxidation. This treatment gave a product containing some metallic iron and a slight deficiency of Cr_2O_3 . The metallic iron was oxidized by heating at 725° C. in a stream of H_2 and H_2O of such composition that the oxidation could proceed to FeO but not to higher oxides.

^{7/} Kelley, K. K., Boericke, F. S., Moore, G. E., Huffman, E. H., and Bangert, W. M., The Thermodynamic Properties of the Carbides of Chromium: Bureau of Mines Tech. Paper 662, 1944, 43 pp.

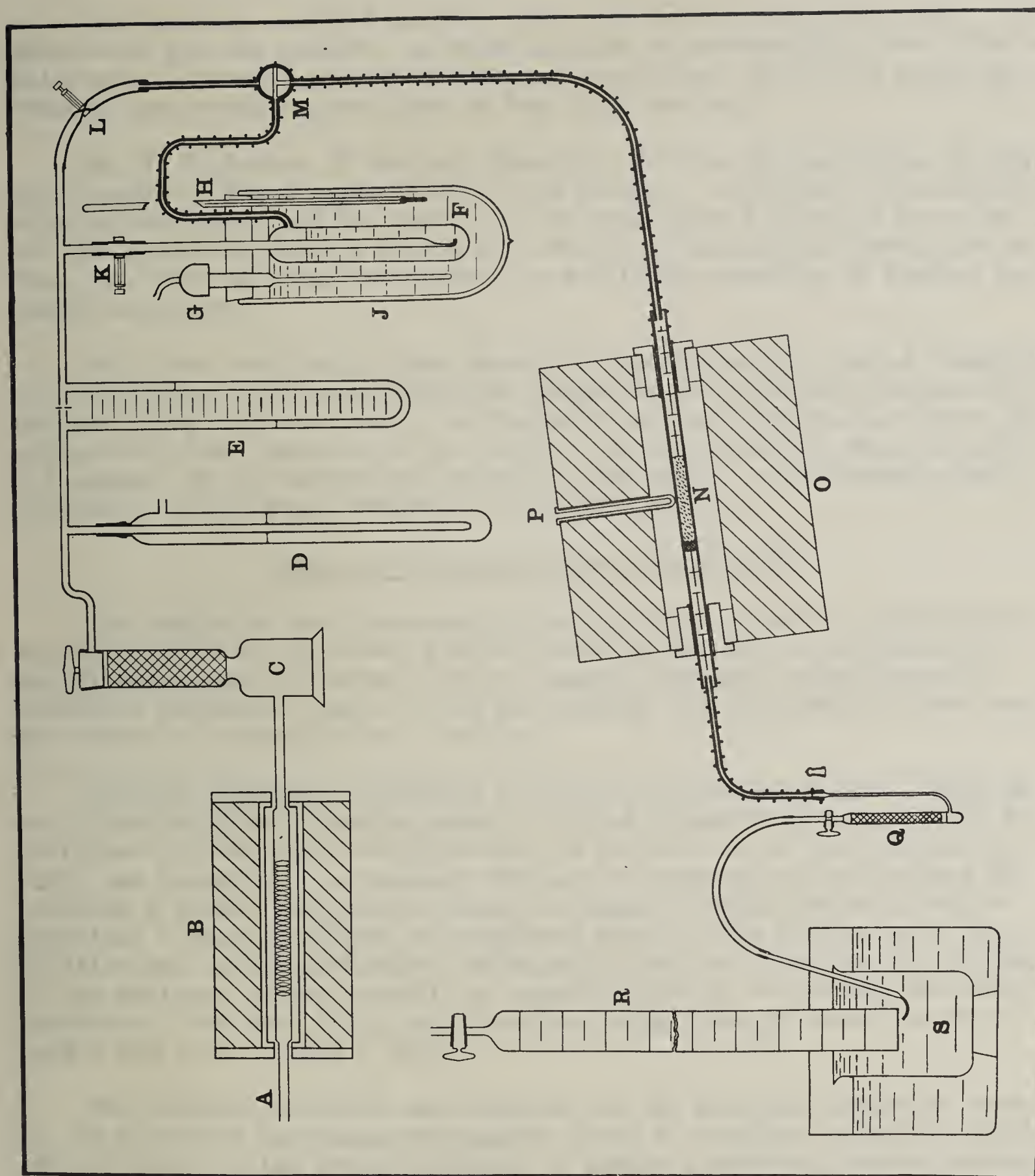


FIGURE 1.- Apparatus for equilibrium measurements in the reaction, $\text{FeO} \cdot \text{Cr}_2\text{O}_3 + \text{H}_2 = \text{Fe} + \text{Cr}_2\text{O}_3 + \text{H}_2\text{O}$.

Figure 1. Schematic diagram of the proposed system.



The Cr_2O_3 content was adjusted, and the mixture was reground and reheated for 12 hours at $1,300^\circ$ to $1,350^\circ$ C. under vacuum in a porcelain tube to obtain the final product.

The material analyzed 31.89 percent FeO and 67.36 percent Cr_2O_3 . No uncombined FeO was present, as shown by lack of acid-soluble iron. The remaining 0.75 percent was either SiO_2 or a silicate, the source being presumably the porcelain tube used in the final heating.

Dr. E. V. Potter of the Salt Lake City Station of the Bureau of Mines kindly made an X-ray examination of the product. He states, "The diffraction pattern contained ten lines, all of which were typical of chromite, and the parameter checked within 0.5 percent of that for synthetic chromite. No other material was present in sufficient quantity to produce any additional lines."

The X-ray examination, the absence of uncombined FeO, and a comparison of the analyses with the theoretical values of 32.09 percent FeO and 67.91 percent Cr_2O_3 indicate that it is unlikely that any appreciable amount of unreacted oxides remained in the sample. As the FeO: Cr_2O_3 ratio is within 0.2 percent of the theoretical value for $\text{FeO}\cdot\text{Cr}_2\text{O}_3$, it is probable that the purity of the final product is near 99.2 percent.

Apparatus for Equilibrium Measurements

The apparatus used in measuring the hydrogen reduction equilibria is shown in figure 1. A steady flow of purified hydrogen or a mixture of purified hydrogen and water vapor was passed through a heated mass of synthetic chromite. Water in the gas issuing from the reaction tube was determined by absorption and weighing.

Cylinder hydrogen containing less than 0.5 percent oxygen, entering at A, was purified by passing over a coil of copper wire held at 700° C. in furnace B, the water being removed in tower C, which was filled with CaCl_2 and Dehydrite. A constant pressure of hydrogen was maintained by allowing a small, continuous stream to escape through bubbler D, which contained a column of H_2SO_4 of regulated height. The flow rate of the purified and dried hydrogen was measured by orifice flowmeter E. Beyond E, the hydrogen passed directly to reaction tube N, or through the water saturator F and then to N, the direction being fixed by three-way stop-cock M and pinch clamps K and L.

The powdered chromite was contained in the porcelain reaction tube N at the center of the Globar furnace O. Tube N contained radiation shields on both sides of the chromite charge to assure a constant temperature-reaction zone. Furnace O was maintained at constant temperature $\pm 2^\circ$ C. by a Leeds & Northrup temperature controller connected to a Pt, Pt-Rh thermocouple in tube P.

On issuing from the reaction tube, the gas passed through weighing tube Q, which was filled with Dehydrite to absorb the water, and thence into gas burette R, where the residual hydrogen volume was measured. A constant back pressure of 2 inches of water was maintained by allowing the water displaced by hydrogen in R to overflow the top of beaker S into the surrounding bath.

This back pressure, together with the head pressure maintained by bubbler D, was sufficient for holding a virtually constant flow rate throughout the course of each experiment. Weighing tube Q was replaced by an auxiliary bubbler (not shown) during adjustment of gas-flow rate prior to an experiment. After the desired flow rate was established, at least 50 cc. of gas was passed before the weighing tube and gas burette were reconnected to the system.

In studying the reaction from the oxidation side, a constant proportion of water, in excess of the equilibrium amount, was added to the hydrogen stream by saturator F by maintaining the temperature of the water in Dewar flask J at the desired value (in the range 50° to 64° C.) with immersion heater G. Before using the saturator, tests were made to prove that the hydrogen actually was saturated with water at the temperature inside J. Condensation of water in the capillary tubes leading to and from reaction tube N was prevented by heat generated electrically in nichrome-wire spirals wound on the capillary tubes.

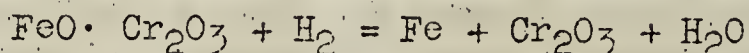
Gas-tight joints were made between the capillary glass tubes and porcelain reaction tube by filling the annular space between them with quick-setting dental cement covered with several coats of bakelite varnish. The last coat was applied to the heated joints while a slight vacuum was maintained in the system.

Weighing tube Q was weighed while its free space contained hydrogen at one atmosphere pressure. Outward diffusion of hydrogen was prevented by a stopcock on one outlet and a tapered ground-glass cap (indicated in the figure) on the other.

A glass counterpoise having about the same surface area was used in weighing, time being allowed for both the counterpoise and tube Q to reach the temperature of the balance case.

RESULTS OF EQUILIBRIUM MEASUREMENTS

The speed of the reaction



was found to be very slow in either direction, even at the highest temperature studied, 1,417° C. Equilibrium could not be established definitely at temperatures much below 1,300° C., although many experiments were conducted at temperatures as low as 500° C. In working from the hydrogen side at

these lower temperatures, erratic results always were obtained. Two opposing effects appeared; (1) at low hydrogen flow rates, the measured water content could be above the equilibrium value because of diffusion of water to colder parts of the reaction tube,^{8/} and (2) at higher hydrogen flow rates, the measured water content could be below the equilibrium value as a result of low reaction rate. In working from the water side at these lower temperatures, the iron was oxidized, but chromite was not formed. This agrees with observations made while preparing the chromite; a temperature of $1,300^{\circ}$ C. was required to obtain a reasonable reaction rate between the oxides.

At temperatures above $1,300^{\circ}$ C., equilibrium could be approached and measured from both directions. The operating data for experiments conducted at temperatures between $1,300^{\circ}$ and $1,417^{\circ}$ C. are recorded in table 1. Column (5) indicates the $H_2O:H_2$ ratio of the gas before contacting chromite in experiments from the water side of the equilibrium point. Column (6) shows the volume of hydrogen, calculated to 0° C. and 760 mm. pressure, that was passed in the time recorded in column (4). In column (7) the amount of water carried by the hydrogen in column (6) is recorded in terms of its gaseous volume at 0° C. and 760 mm. pressure. Column (8)

gives the resulting values of $K = \frac{\text{vol. } H_2O}{\text{vol. } H_2} = \frac{P_{H_2O}}{P_{H_2}}$. The direction from which equilibrium was approached is indicated in column (3), in which r and l refer to the right and left sides of the reaction equation as written at the top of the table.

The values of K for each temperature show a spread of about 15 percent. Excepting the determinations at $1,300^{\circ}$ to $1,309^{\circ}$ C., examination of the data shows that the variations in K are random and not systematically connected with variations of gas-flow rate or direction of approach to equilibrium. Further examination of the data is inherent in the Σ -function calculations of the next section.

THERMODYNAMIC PROPERTIES OF FERROUS CHROMITE

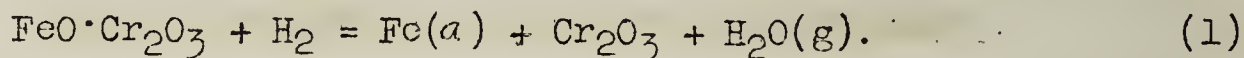
Before attempting thermodynamic calculations from the data of table 1, it is desirable to record the basic thermal data that will be employed in this and the following sections of this report. These data are collected in table 2.

^{8/} This effect has been discussed by Emmett, P. and Schultz, J. F., Gaseous Thermal Diffusion - The Principal Cause of Discrepancy Among Equilibrium Measurements on the Systems: $Fe_3O_4-H_2-Fe-H_2O$, $Fe_3O_4-H_2-FeO-H_2O$, and $FeO-H_2-Fe-H_2O$: Jour. Am. Chem. Soc., vol. 55, 1933, p. 1376.

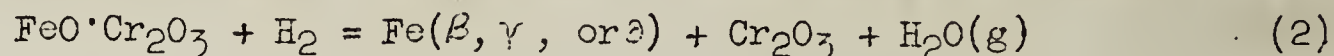
TABLE 1. - Equilibrium measurements in the reaction,
 $\text{FeO} \cdot \text{Cr}_2\text{O}_3 + \text{H}_2 = \text{Fe} + \text{Cr}_2\text{O}_3 + \text{H}_2\text{O(g)}$

| Run | Temp., °C. | Direction of reaction | Time, hrs. | Input, H ₂ O/H ₂ ratio | Vol. dry H ₂ at N.T.P. | Vol. H ₂ O at N.T.P. | $K = P_{\text{H}_2\text{O}}/P_{\text{H}_2}$ |
|----------|---------------|-----------------------------|---------------|--|---|---------------------------------------|---|
| 1 | 1,300 | l to r | 15.5 | - | 534.1 | 35.95 | 0.0673 |
| 2 | 1,300 | l to r | 9.25 | - | 535.7 | 34.21 | .0639 |
| 3 | 1,300 | l to r | 15.5 | - | 468.3 | 33.84 | .0723 |
| 4 | 1,301 | l to r | 5 | - | 443.2 | 27.00 | .0609 |
| 5 | 1,309 | r to l | 15.25 | 0.27 | 240.6 | 19.66 | .0817 |
| 6 | 1,356 | r to l | 24 | .28 | 507.1 | 39.68 | .0782 |
| 7 | 1,356 | r to l | 20 | .30 | 502.7 | 39.56 | .0787 |
| 8 | 1,356 | l to r | 24 | - | 529.2 | 49.51 | .0936 |
| 9 | 1,356 | l to r | 18 | - | 505.5 | 43.54 | .0861 |
| 10 | 1,381 | l to r | 8.25 | - | 560.9 | 53.49 | .0954 |
| 11 | 1,381 | l to r | 15.25 | - | 531.6 | 52.25 | .0983 |
| 12 | 1,381 | l to r | 8 | - | 571.9 | 48.39 | .0846 |
| 13 | 1,381 | l to r | 7 | - | 527.1 | 44.04 | .0836 |
| 14 | 1,389 | r to l | 5.25 | 0.23 | 349.3 | 29.86 | .0855 |
| 15 | 1,417 | l to r | 3.5 | - | 530.0 | 48.76 | .0920 |
| 16 | 1,417 | l to r | 17.5 | - | 526.5 | 52.50 | .0997 |
| 17 | 1,417 | l to r | 7 | - | 526.0 | 49.88 | .0948 |
| 18 | 1,417 | l to r | 13.5 | - | 557.0 | 54.36 | .0976 |
| 19 | 1,417 | l to r | 6 | - | 523.2 | 46.28 | .0885 |
| 20 | 1,417 | r to l | 7.25 | 0.15 | 552.3 | 46.65 | .0845 |
| 21 | 1,417 | r to l | 19 | .18 | 451.6 | 41.55 | .0920 |

To obtain the thermodynamic properties of $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ at the standard temperature, 298.2° K., it will be necessary to consider the reaction



The data of table 1 involve formation of iron in the γ and δ ranges, and therefore the reaction



must be considered first. In accordance with Appendix A, the simple, composite specific heat equation for $\text{Fe}(\beta, \gamma, \text{ or } \delta)$, given in table 2, is employed. The pertinent specific-heat equations and entropies of reactants and products result in the following expression, which holds for reaction (2) and the data of table 1:

$$\Sigma = -R \ln K - 0.875 \log T - 0.59 \times 10^{-3} T + 1.942 \times 10^5 T^{-2} = \frac{\Delta H_0}{T} - 8.11$$

The derivation of this equation and details of subsequent calculations are in Appendix B.

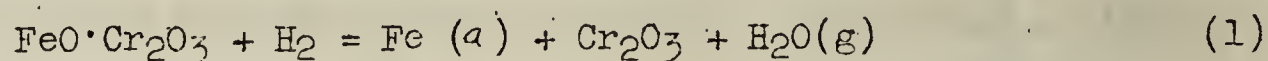
TABLE 2. - Basic thermodynamic data

| Substance | $S^{\circ}_{298.16}$ | $\Delta H_{298.16}$ | C_p -equation |
|--|--------------------------------|----------------------------------|---|
| Fe(α) | $\underline{2}/6.49 \pm 0.03$ | - | $C_p = 4.13 + 6.38 \times 10^{-3} T \underline{10}/$ |
| Fe(β , γ , or δ) | - | - | $C_p = 9.672 \underline{11}/$ |
| Cr(s) | $\underline{5}/5.68 \pm 0.07$ | - | $C_p = 5.84 + 2.362 \times 10^{-3} T - 0.875 \times 10^5 T^{-2} \underline{7}/$ |
| H ₂ (g) | $\underline{2}/31.23 \pm 0.01$ | - | $C_p = 6.62 + 0.81 \times 10^{-3} T \underline{10}/$ |
| C (graphite) | $\underline{2}/1.36 \pm 0.03$ | - | $C_p = 4.106 + 1.024 \times 10^{-3} T - 2.090 \times 10^5 T^{-2} \underline{7}/$ |
| O ₂ (g) | $\underline{2}/49.03 \pm 0.01$ | - | $C_p = 8.27 + 0.258 \times 10^{-3} T - 1.877 \times 10^5 T^{-2} \underline{10}/$ |
| FeO(s) | $\underline{5}/13.4 \pm 1.0$ | $\underline{12}/-64,250 \pm 300$ | $C_p = 12.62 + 1.492 \times 10^{-3} T - 0.762 \times 10^5 T^{-2} \underline{10}/$ |
| Cr ₂ O ₃ (s) ... | $\underline{2}/19.4 \pm 0.3$ | $\underline{7}/-270,700 \pm 900$ | $C_p = 28.53 + 2.20 \times 10^{-3} T - 3.736 \times 10^5 T^{-2} \underline{7}/$ |
| H ₂ O(g) | $\underline{2}/45.13 \pm 0.01$ | $\underline{13}/-57,798 \pm 10$ | $C_p = 7.00 + 2.77 \times 10^{-3} T \underline{14}/$ |
| CO(g) | $\underline{2}/47.32 \pm 0.01$ | $\underline{13}/-26,394 \pm 31$ | $C_p = 6.60 + 1.20 \times 10^{-3} T \underline{10}/$ |
| CO ₂ (g) | $\underline{2}/51.08 \pm 0.01$ | $\underline{13}/-94,030 \pm 46$ | $C_p = 10.34 + 2.74 \times 10^{-3} T - 1.955 \times 10^5 T^{-2} \underline{10}/$ |
| FeO·Cr ₂ O ₃ (s) | $\underline{15}/34.9 \pm 0.7$ | - | $C_p = 38.96 + 5.34 \times 10^{-3} T - 7.619 \times 10^5 T^{-2} \underline{16}/$ |
| Fe ₃ C(α) | $\underline{2}/24.2 \pm 1.5$ | $\underline{17}/5,500 \pm 1,600$ | $C_p = 21.55 + 15.06 \times 10^{-3} T \underline{17}/$ |
| Fe ₃ C(β) | - | $\underline{17}/5,780 \pm 1,700$ | $C_p = 27.01 + 1.46 \times 10^{-3} T \underline{17}/$ |
| CH ₄ (g) | $\underline{5}/44.5 \pm 0.1$ | $\underline{17}/-18,050 \pm 50$ | $C_p = 6.73 + 10.20 \times 10^{-3} T - 1.118 \times 10^5 T^{-2} \underline{17}/$ |

- 9/ Kelley, K. K., The Specific Heat of Pure Iron at Low Temperatures: Jour. Chem. Phys., vol. 11, 1943, p. 16.
- 10/ Kelley, K. K., Contributions to the Data on Theoretical Metallurgy. II. High-Temperature Specific-Heat Equations for Inorganic Substances: Bureau of Mines Bull. 371, 1933, 78 pp.
- 11/ This equation is derived in Appendix A.
- 12/ Kelley, K. K., Contributions to the Data on Theoretical Metallurgy. VII. The Thermodynamic Properties of Sulfur and its Inorganic Compounds. Bureau of Mines Bull. 406, 1937, 154 pp.
- 13/ Rossini, F. D., Heat and Free Energy of Formation of Water and Carbon Monoxide: Nat. Bur. Stands. Jour. Res., vol. 22, 1939, p. 407.
- 14/ Kelley, K. K., and Anderson, C. T., Contributions to the Data on Theoretical Metallurgy. IV. Metal Carbonates - Correlations and Applications of Thermodynamic Properties: Bureau of Mines Bull. 384, 1935, 73 pp.
- 15/ Shomate, C. H., Ferrous and Magnesium Chromites, Specific Heats at Low Temperatures: Ind. Eng. Chem., vol. 36, 1944, p. 910.
- 16/ Naylor, B. F., High-Temperature Heat Contents of Ferrous and Magnesium Chromites: Ind. Eng. Chem., vol. 36, 1944, p. 933.
- 17/ Kelley, K. K., Contributions to the Data on Theoretical Metallurgy. VIII. The Thermodynamic Properties of Metal Carbides and Nitrides: Bureau of Mines Bull. 407, 1937, 66 pp.

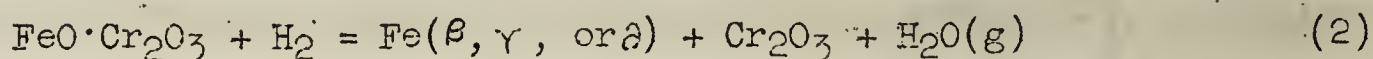
Table 3 shows the application of this Σ - function to the experimental data of table 1 in the evaluation of the constant, ΔH_o , of the free-energy equation for reaction (2). The mean value is $\Delta H_o = 15,300$, and the average deviation from the mean is 210. The total spread in the ΔH_o values is 910, but 14 of the 21 individual values lie within the range of ± 210 from the mean. Also, it is noted that there is no systematic trend in ΔH_o with temperature. Averaging the individual groups, as segregated in table 3, leads to the following values of ΔH_o in passing from the lowest to the highest temperatures: 15,400, 15,200, 15,200, and 15,400. It appears, therefore, that $\Delta H_o = 15,300 \pm 200$ calories is a reasonable assignment of both the magnitude and the uncertainty.

The heat and free-energy equations for reactions (1) and (2), derived as indicated in Appendix B, follow:



$$\Delta H = 17,270 - 5.92T + 2.60 \times 10^{-3}T^2 - 3.883 \times 10^5 T^{-1} \quad (1A)$$

$$\Delta F^\circ = 17,270 + 13.63 T \log T - 2.60 \times 10^{-3}T^2 - 1.942 \times 10^5 T^{-1} - 45.17T \quad (1B)$$



$$\Delta H = 15,300 - 0.38T - 0.59 \times 10^{-3}T^2 - 3.883 \times 10^5 T^{-1} \quad (2A)$$

$$\Delta F^\circ = 15,300 + 0.875T \log T + 0.59 \times 10^{-3}T^2 - 1.942 \times 10^5 T^{-1} - 8.11T \quad (2B)$$

Values of ΔH , ΔF° , and $K = \frac{P_{\text{H}_2\text{O}}}{P_{\text{H}_2}}$, computed from these equations at even temperatures, are listed in table 4. It is obvious that hydrogen is not an effective reducing agent for the iron in chromite. Even at $1,700^\circ \text{K}$., only about 10 percent of the hydrogen would react in this manner. The equilibrium constants of table 4 are lower than corresponding values for the hydrogen reduction of free ferrous oxide by factors ranging from 72 to 10 between $1,000^\circ$ and $1,700^\circ \text{K}$.

The value $\Delta H_{298.2} = 14,430$ for reaction (1) and the pertinent data of table 1 lead to the thermodynamic values given in table 5 for the formation of $\text{FeO} \cdot \text{Cr}_2\text{O}_3$. The heat of formation from the oxides, $\Delta H_{298.2} = -8,000 \pm 500$ cal. per mole, shows order of magnitude agreement with the value, ^{18/} $-6,900$ cal. per mole, for the formation of $\text{Fe}_3\text{O}_4(\text{FeO} \cdot \text{Fe}_2\text{O}_3)$ from FeO and Fe_2O_3 .

^{18/} Landolt-Bornstein, Physikalisch-Chemische Tabellen: Julius Springer, Berlin, Third Suppl., vol. 3, 1936, p. 2774.

TABLE 3. - Calculation of ΔH_o for reaction (2). $\Sigma = -R \ln K - 0.875 \log T - 0.59 \times 10^{-3} T + 1.942 \times 10^5 T^{-2} = \frac{\Delta H_o}{T} - 8.11$

| Run | T°, K. | K | -R ln K | -0.875 log T | -0.59x10 ⁻³ T | 1.942x10 ⁵ T ⁻² | Σ | $\Sigma + 8.11$ | ΔH_o |
|------------------------|--------|--------|---------|--------------|--------------------------|---------------------------------------|----------|-----------------|--------------|
| 1 | 1,573 | 0.0673 | 5.362 | -2.797 | -0.928 | +0.078 | 1.72 | 9.83 | 15,460 |
| 2 | 1,573 | .0639 | 5.463 | -2.797 | - .928 | + .078 | 1.82 | 9.93 | 15,620 |
| 3 | 1,573 | .0723 | 5.220 | -2.797 | - .928 | + .078 | 1.57 | 9.68 | 15,230 |
| 4 | 1,574 | .0609 | 5.559 | -2.797 | - .929 | + .078 | 1.91 | 10.02 | 15,770 |
| 5 | 1,582 | .0817 | 4.978 | -2.799 | - .933 | + .078 | 1.32 | 9.43 | 14,920 |
| 6 | 1,629 | .0782 | 5.065 | -2.810 | - .961 | + .073 | 1.37 | 9.48 | 15,440 |
| 7 | 1,629 | .0787 | 5.051 | -2.810 | - .961 | + .073 | 1.35 | 9.46 | 15,410 |
| 8 | 1,629 | .0936 | 4.708 | -2.810 | - .961 | + .073 | 1.01 | 9.12 | 14,860 |
| 9 | 1,629 | .0861 | 4.872 | -2.810 | - .961 | + .073 | 1.17 | 9.28 | 15,120 |
| 10 | 1,654 | .0954 | 4.666 | -2.816 | - .976 | + .071 | .95 | 9.06 | 14,990 |
| 11 | 1,654 | .0983 | 4.607 | -2.816 | - .976 | + .071 | .89 | 9.00 | 14,890 |
| 12 | 1,654 | .0846 | 4.909 | -2.816 | - .976 | + .071 | 1.19 | 9.30 | 15,380 |
| 13 | 1,654 | .0836 | 4.932 | -2.816 | - .976 | + .071 | 1.21 | 9.32 | 15,420 |
| 14 | 1,662 | .0855 | 4.886 | -2.818 | - .981 | + .070 | 1.16 | 9.27 | 15,410 |
| 15 | 1,690 | .0920 | 4.740 | -2.824 | - .997 | + .068 | .99 | 9.10 | 15,380 |
| 16 | 1,690 | .0997 | 4.580 | -2.824 | - .997 | + .068 | .83 | 8.94 | 15,110 |
| 17 | 1,690 | .0948 | 4.680 | -2.824 | - .997 | + .068 | .93 | 9.04 | 15,280 |
| 18 | 1,690 | .0976 | 4.625 | -2.824 | - .997 | + .068 | .87 | 8.98 | 15,180 |
| 19 | 1,690 | .0885 | 4.817 | -2.824 | - .997 | + .068 | 1.06 | 9.17 | 15,500 |
| 20 | 1,690 | .0845 | 4.909 | -2.824 | - .997 | + .068 | 1.16 | 9.27 | 15,670 |
| 21 | 1,690 | .0920 | 4.740 | -2.824 | - .997 | + .068 | .99 | 9.10 | 15,380 |
| Average $\Delta H_o =$ | | | | | | | | | 15,300 |

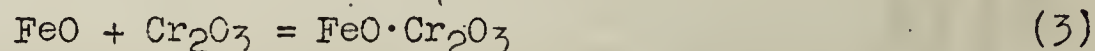
TABLE 4. - Thermodynamic values for the reaction
 $\text{FeO} \cdot \text{Cr}_2\text{O}_3 + \text{H}_2 = \text{Fe} + \text{Cr}_2\text{O}_3 + \text{H}_2\text{O}(\text{g})$

| T° K. | Type of iron | ΔH cal./mole: | ΔF° cal./mole | $K = \frac{P_{\text{H}_2\text{O}}}{P_{\text{H}_2}}$ |
|-----------|--------------|-----------------------|----------------------------|---|
| 298.2.. | α | 14,430 | 12,970 | 3.11×10^{-10} |
| 1,000.... | α | 13,560 | 10,200 | 5.89×10^{-3} |
| 1,200.... | γ | 13,670 | 9,490 | 1.87×10^{-2} |
| 1,300.... | γ | 13,510 | 9,150 | 2.90×10^{-2} |
| 1,400.... | γ | 13,340 | 8,820 | 4.20×10^{-2} |
| 1,500.... | γ | 13,140 | 8,500 | 5.77×10^{-2} |
| 1,600.... | γ | 12,940 | 8,200 | 7.59×10^{-2} |
| 1,700.... | δ | 12,720 | 7,910 | 9.62×10^{-2} |

TABLE 5. - Thermodynamic values for the formation of
 $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ at 298.2° K.

| | ΔH° | ΔS° | ΔF° |
|--|----------------------|------------------|----------------------|
| From elements | $-342,900 \pm 1,000$ | -81.0 ± 0.7 | $-318,700 \pm 1,000$ |
| From FeO and Cr_2O_3 ... | $-8,000 \pm 500$ | 2.1 ± 1.3 | $-8,630 \pm 600$ |

The data of table 5 and specific-heat equations of table 1 suffice for deriving heat and free-energy equations for the formation of $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ from either the elements or the constituent oxides. The results in the latter instance, obtained by conventional methods, are:



$$\Delta H = -8,470 - 2.19T + 0.825 \times 10^{-3}T^2 + 3.121 \times 10^5 T^{-1} \quad (3A)$$

$$\Delta F^\circ = -8,470 + 5.04T \log T - 0.825 \times 10^{-3}T^2 + 1.560 \times 10^5 T^{-1} - 14.52T \quad (3B)$$

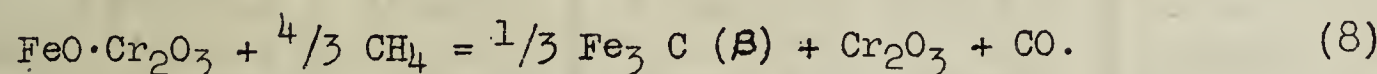
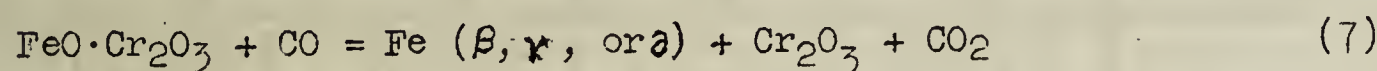
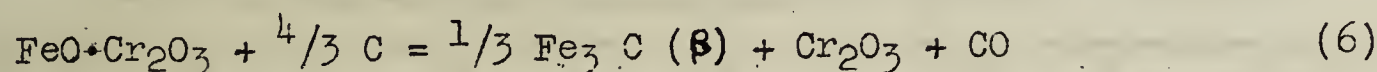
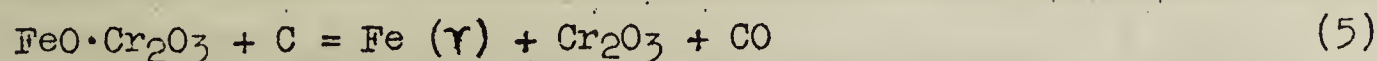
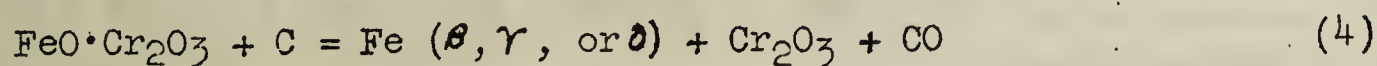
Values from equations (3A) and (3B) are listed in table 6. It is apparent that the stability of chromite changes very slowly with temperature. At 1,700° K., it is nearly as stable with respect to the oxides as at 298° K. This accounts in part for the high temperature required for the selective reduction of iron in chromite and for some uses of chromite refractories.

TABLE 6. - Thermodynamic values for the reaction,
 $\text{FeO} + \text{Cr}_2\text{O}_3 = \text{FeO} \cdot \text{Cr}_2\text{O}_3$

| T° K. | ΔH | ΔF° |
|-------------|------------|------------------|
| 298.2 | -8,000 | -8,630 |
| 1,000 | -9,500 | -8,500 |
| 1,200 | -9,600 | -8,300 |
| 1,300 | -9,700 | -8,200 |
| 1,400 | -9,700 | -8,100 |
| 1,500 | -9,700 | -8,000 |
| 1,600 | -9,700 | -7,900 |
| 1,700 | -9,600 | -7,800 |

OTHER SELECTIVE REDUCTION REACTIONS OF CHROMITE

As a direct consequence of the determination of the thermodynamic properties of ferrous chromite described in the preceding section, it is now possible for the first time to derive heat and free-energy equations for other reactions involving chromite. Five of these reactions will be considered:



The data of tables 2 and 5 and the value $\Delta H_{463} = 325$ for the heat absorption in the transformation $\text{Fe}_3\text{C} (\alpha) = \text{Fe}_3\text{C} (\beta)$ are used throughout. The derived expressions for each reaction are of the general types indicated below:

$$\Delta C_p = a + b T - CT^{-2}$$

$$\Delta H = \Delta H_0 + a T + \frac{b}{2} T^2 + CT^{-1}$$

$$\Delta S = a + 2.303a \log T + b T + \frac{C}{2} T^{-2}$$

$$\Delta F^\circ = \Delta H_0 - 2.303a T \log T - \frac{b}{2} T^2 + \frac{C}{2} T^{-1} + IT$$

$$\Delta F^\circ = -RT \ln K = -4.575 T \log K.$$

Table 7 lists the values of the constants in the free-energy equations. The other equations may be obtained readily by inspection.

In tables 8, 9, and 10 may be found, respectively, values of ΔF° , values of K , and values of ΔH for reactions (4) to (8) at temperatures from 1,100° to 1,700° K. The subscript number in each instance corresponds to the equation number.

TABLE 7. - Free-energy equations of reactions (4) to (8)

| Reaction | ΔH_0 | $-2.303a$ | $-b/2$ | $\frac{C}{2}$ | I. |
|-----------|--------------|-----------|-----------------------|----------------------|--------|
| (4) | 46,830 | -3.98 | 1.48×10^{-3} | -2.986×10^5 | -27.76 |
| (5) | 48,700 | -1.06 | 1.48×10^{-3} | -2.986×10^5 | -38.32 |
| (6) | 50,180 | .69 | 1.41×10^{-3} | -3.335×10^5 | -44.86 |
| (7) | 3,790 | -6.86 | 0.80×10^{-3} | -0.964×10^5 | 25.51 |
| (8) | 70,050 | -31.90 | 6.44×10^{-3} | -2.687×10^5 | 21.91 |

TABLE 8. - Free-energy values (cal. per mole)

| T°, K. | ΔF_4^0 | ΔF_5^0 | ΔF_6^0 | ΔF_7^0 | ΔF_8^0 |
|-------------|----------------|----------------|----------------|----------------|----------------|
| 1,100 | 4,500 | - | 4,500 | 9,800 | - 5,000 |
| 1,200 | 700 | 700 | 600 | 10,100 | -12,500 |
| 1,300 | -3,100 | -3,100 | -3,200 | 10,500 | -19,900 |
| 1,400 | -6,900 | -6,900 | -7,100 | 10,800 | -27,400 |
| 1,500 | -10,600 | -10,700 | -10,900 | 11,100 | -34,800 |
| 1,600 | -14,400 | -14,400 | -14,600 | 11,400 | -42,100 |
| 1,700 | -18,100 | - | -18,400 | 11,700 | -49,400 |

TABLE 9. - Equilibrium constants of reactions (4) to (8)

| T°, K. | K ₄ | K ₅ | K ₆ | K ₇ | K ₈ |
|-------------|----------------------|----------------------|----------------------|----------------------|---------------------|
| 1,100 | 1.3x10 ⁻¹ | - | 1.3x10 ⁻¹ | 1.1x10 ⁻² | 1.0 |
| 1,200 | 7.4x10 ⁻¹ | 7.4x10 ⁻¹ | 7.8x10 ⁻¹ | 1.4x10 ⁻² | 1.9x10 ² |
| 1,300 | 3.3 | 3.3 | 3.5 | 1.7x10 ⁻² | 2.2x10 ³ |
| 1,400 | 1.2x10 ¹ | 1.2x10 ¹ | 1.3x10 ¹ | 2.1x10 ⁻² | 1.9x10 ⁴ |
| 1,500 | 3.5x10 ¹ | 3.6x10 ¹ | 3.9x10 ¹ | 2.4x10 ⁻² | 1.2x10 ⁵ |
| 1,600 | 9.3x10 ¹ | 9.3x10 ¹ | 9.9x10 ¹ | 2.8x10 ⁻² | 5.6x10 ⁵ |
| 1,700 | 2.1x10 ² | - | 2.3x10 ² | 3.1x10 ⁻² | 2.2x10 ⁶ |

TABLE 10. - Heats of reaction (cal. per mole)

| T°, K. | ΔH_4 | ΔH_5 | ΔH_6 | ΔH_7 | ΔH_8 |
|-------------|--------------|--------------|--------------|--------------|--------------|
| 1,100 | 46,400 | - | 47,500 | 5,900 | 77,000 |
| 1,200 | 46,300 | 46,600 | 47,200 | 6,000 | 76,900 |
| 1,300 | 46,100 | 46,300 | 46,900 | 6,200 | 76,800 |
| 1,400 | 45,900 | 46,000 | 46,500 | 6,300 | 76,400 |
| 1,500 | 45,700 | 45,700 | 46,100 | 6,300 | 76,000 |
| 1,600 | 45,400 | 45,300 | 45,700 | 6,400 | 75,400 |
| 1,700 | 45,100 | - | 45,200 | 6,400 | 74,700 |

Reactions (4), (5), and (6) pertain to the selective reduction of iron in chromite by carbon, the principal step in a method of chemically beneficiating low-grade chromite ores. Values in tables 8 and 9 show that these reactions are potentially effective at temperatures above about 1,220° K. In each reaction, K is equal to P_{CO} , the partial pressure of CO expressed in atmospheres. One atmosphere is reached by reactions (4) and (5) at 1,218° K. and by reaction (6) at 1,217° K. It is evident from table 2 that values for reaction (6) are much less accurate than those for reactions (4) and (5), and the indication in tables 8 and 9 that reaction (6) is favored over reactions (4) and (5) at temperatures above 1,200° K. would be questionable, were it not for the fact that this has been substantiated by chemical analyses of reduction products. Actually, however, it makes but little difference which viewpoint is taken insofar as the energy requirement (table 10) or the equilibrium pressure (table 9) are concerned.

In laboratory and pilot-plant tests,^{19/} temperatures in the range $1,573^{\circ}$ to $1,673^{\circ}$ K. ($1,300^{\circ}$ to $1,400^{\circ}$ C.) have been found necessary for the selective reduction of the iron in chromite by carbon within a reasonable time. The present calculations show that this is a matter of obtaining a rapid enough reaction rate and not a matter of obtaining an adequate equilibrium partial pressure of CO. A comparison of the values in tables 8, 9, and 10 for reactions (4) and (5) indicates the magnitude of error involved in using the composite specific-heat equation for δ , γ , and β iron.

The values for reaction (5) were calculated by using the separate specific-heat equations and heats of transition of α , β , and γ -iron derived by Kelley,^{10/} and are in good agreement with those for reaction (4), calculated with the composite equation. This comparison justifies the use of the composite equation for β , γ , and δ -Fe in all practical metallurgical calculations involving iron in the temperature range $1,041^{\circ}$ to $1,803^{\circ}$ K.

Reaction (7) is of interest, as it would be expected to accompany reactions (4), (5), and (6). The calculations show, however, that CO is not an effective reducing agent for chromite. The maximum amount of CO reacting in this manner in the temperature range $1,100^{\circ}$ to $1,700^{\circ}$ K. is seen from table 9 to be about 3 percent at $1,700^{\circ}$ K. Consequently, for practical purposes, the gas produced in the selective reduction of chromite by carbon may be considered as being entirely CO.

Reaction (8) is considered to represent the main over-all reaction in the selective reduction of the iron in chromite by methane. Experimental evidence of small-scale tests, to be published elsewhere, indicates Fe_3C rather than iron is produced in the methane reduction. This, also, is in accord with the best thermodynamic data available at present. Small-scale tests of this reaction have shown it to be effective in the temperature range $1,273^{\circ}$ to $1,373^{\circ}$ K. ($1,000^{\circ}$ to $1,100^{\circ}$ C.). The figures in tables 8 and 9 show it to be potentially effective at temperatures as low as $1,200^{\circ}$ K. at a total pressure of one atmosphere. The higher temperature required in the tests, therefore, appears to be connected with reaction rate.

The smaller difference between actual and theoretical effective temperatures of reaction (8), as compared with reactions (4), (5), and (6), is to be expected, in view of the ease of obtaining contact between a gas and a solid as compared with contact between two solids. At temperatures in the range $1,273^{\circ}$ to $1,373^{\circ}$ K., calculations show that at a total pressure of 1 atmosphere virtually all the methane would react before equilibrium is reached. (It is recognized that reaction (8) must compete with the straight cracking reaction of methane. Experiments have shown that dilution of methane by hydrogen will virtually eliminate the cracking reaction if conditions are properly controlled.) Recalling previous calculations, which showed both hydrogen and carbon monoxide to be ineffective reducing agents for chromite, it is apparent that the gas produced in the methane-chromite reaction may be considered as essentially a mixture of carbon monoxide and hydrogen.

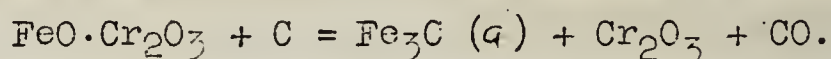
^{19/} Reference is made here to tests conducted at the Salt Lake City, Boulder City, and Berkeley stations of the Bureau of Mines.

SOME GENERAL CALCULATIONS OF THE ENERGY REQUIRED IN THE SELECTIVE CARBON-REDUCTION OF A TYPICAL LOW-GRADE CHROMITE

The total energy required in any process depends on several factors, including provisions for preventing heat losses by radiation, conduction, and convection, provisions for recovering sensible heat from all products of reaction (including combustion products, if fuel is used), and the thermochemistry of the reactions occurring in the process. Only the last-named factor is independent of the specific method and equipment employed. The present calculations, being limited to this factor, are of general utility.

A typical concentrate of a domestic, low-grade chromite ore from the Benbow property in Montana is considered. It contains 24.0 percent FeO, 41.3 percent Cr₂O₃, 12.9 percent MgO, 18.2 percent Al₂O₃, and 1.6 percent SiO₂.

There will be calculated first the approximate minimum energy required to reduce all the iron in a ton of this chromite to Fe₃C, assuming no heat losses and complete recovery of heat from the reduced product, and ignoring recovery of heat from combustion products of fuel. This minimum requirement is given approximately by $\Delta H_{298.2}$ for the reaction



Data of tables 2 and 5 yield $\Delta H_{298.2} = 47,640$ cal. per gram mole, or 85,750 B.t.u. per pound mole of iron reduced. To reduce all the iron, 374 pounds, or 6.69 pound moles, in a ton of the Benbow concentrates would require 574,000 B.t.u. as a minimum. Any heat supplied in excess of this amount must be considered as lost, and the thermal efficiency of any particular means of carrying out the reduction by carbon may be obtained by dividing this number by the quantity of heat actually supplied.

Another general calculation that can be made is to estimate the total heat required to bring chromite and carbon to reaction temperature and to reduce completely the iron to Fe₃C, no other factors being considered. In computing the first item, some assumption is necessary concerning the degree of departure of the heat content of chromite from the sum of the heat contents of its constituent oxides. Measurements of Naylor^{20/} show that at high temperatures the heat contents of MgO·Cr₂O₃ and FeO·Cr₂O₃ are less than those of the constituent oxides by amounts ranging from 0.4 to 4.2 percent.

It will be assumed that, on the average, the heat content of the Benbow concentrate is 2 percent less than the sum for the oxides. (See appendix C.) The amount of carbon required for reduction of the iron to Fe₃C is computed as 106 pounds per ton of concentrates. Using heat-content data from sources^{21/}

^{20/} See footnote 16.

^{21/} See footnotes 7 and 10.

referred to in an earlier section, the values in lines (2) and (3) of table 11 are computed. The results in line (3) are based upon interpolation of the heats of reaction (6), as listed in table 11.

TABLE 11. - Energy required to heat and reduce
Benbow ore (B.t.u. per ton)

| Temperature of reduction, °C. | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
|--|-----------|-----------|-----------|-----------|-----------|
| To heat 1 ton of ore.. | 757,000 | 840,000 | 925,000 | 1,009,000 | 1,094,000 |
| To heat 106 pounds carbon | 68,000 | 76,000 | 85,000 | 94,000 | 103,000 |
| To reduce 480 pounds FeO (in chromite)... | 566,000 | 561,000 | 557,000 | 552,000 | 547,000 |
| Total, per ton of ore. | 1,391,000 | 1,477,000 | 1,567,000 | 1,655,000 | 1,744,000 |

SUMMARY

A method of making substantially pure, synthetic ferrous chromite is described.

Equilibria in the selective reduction of the iron in ferrous chromite by hydrogen were measured in the temperature range 1,575° to 1,690° K. The results were treated thermodynamically to obtain the heat and free energy of formation of ferrous chromite. Hydrogen was shown to be an ineffective reducing agent for chromite at temperatures up to 1,700° K., the maximum amount reacting before equilibrium is reached being about 10 percent.

The thermodynamic values of ferrous chromite are applied in calculations of selective reduction reactions with carbon, carbon monoxide, and methane.

Calculations show carbon to be potentially effective, selective reducing agent at temperatures above 1,220° K., formation of Fe₃C rather than Fe being favored slightly. Higher temperatures required in practice are the result of low reaction rate.

Calculations show carbon monoxide to be an ineffective selective reducing agent at temperatures up to 1,700°, the maximum amount reacting before equilibrium is reached being about 3 percent.

Calculations show methane to be a potentially effective, selective reducing agent at temperatures above 1,200° K. Higher temperatures are required to obtain a satisfactory reaction rate.

Heat, free energy, and equilibrium-constant equations and values are derived for each of the above-mentioned reactions.

Results of some general calculations of the energy required in the selective reduction by carbon of the iron in a concentrate of a typical, low-grade, domestic chromite ore are listed.

A single composite specific-heat equation was derived to represent the heat contents of β , γ , and δ iron above 273.2° K. This equation is satisfactory for all practical metallurgical calculations.

APPENDIX A

HEAT CONTENT OF IRON

A plot of smooth values of the high-temperature heat content of iron, listed by Kelley,^{22/} shows that in the temperature range from $1,041^\circ$ to $1,803^\circ$ K. the data may be represented fairly satisfactorily by a single straight line of slope $C_p=9.672$. This is illustrated in table 12, in which column (1) gives the temperature, column (2) gives the smooth experimental values of heat content above 273.2° K., column (3) gives values calculated by use of $C_p=9.672$ in lieu of Kelley's equations for the β , γ , and δ ranges. Because of the small transition heats, the greatest discrepancy in heat content involved in the use of this composite equation is 390 cal. per gram atom at $1,179^\circ$ K. The average discrepancy is 140 cal. As seen in tables 8, 9, and 10, partial compensation of the discrepancy will occur in free-energy calculations of any reaction involving iron, as both ΔH and ΔS will deviate in the same direction. Calculations are shortened by the composite equation, as only one heat and entropy of transition need be taken into account. The composite equation is used throughout this report in conjunction with Kelley's equation for α -iron and the heat of transition of α to β iron.

$$\text{Fe}(\alpha): C_p = 4.13 + 6.38 \times 10^{-3} T \quad (273^\circ \text{ to } 1,041^\circ \text{ K.}).$$

$$\text{Fe}(\alpha) = \text{Fe}(\beta); \Delta H_{1041} = 340$$

$$\text{Fe}(\beta, \gamma, \text{ or } \delta): C_p = 9.672$$

$$\text{Fe}(\delta) = \text{Fe}(1); \Delta H_{1803} = 3,560$$

$$\text{Fe}(1): C_p = 8.15$$

TABLE 12. - Heat content of Fe above 273.2° K.
(cal. per gram atom)

| $T^\circ, \text{ K.}$ | Smooth experimental results | Values from Kelley's equations | Values from composite equation |
|-----------------------|-----------------------------------|-----------------------------------|--------------------------------------|
| 298.2 | 150 | 149 | 149 |
| 373 | 610 | 618 | 618 |
| 473 | 1,270 | 1,300 | 1,300 |
| 573 | 2,010 | 2,045 | 2,045 |
| 673 | 2,830 | 2,860 | 2,860 |
| 773 | 3,715 | 3,730 | 3,730 |
| 873 | 4,670 | 4,670 | 4,670 |
| 973 | 5,750 | 5,670 | 5,670 |

^{22/} See footnote 10.

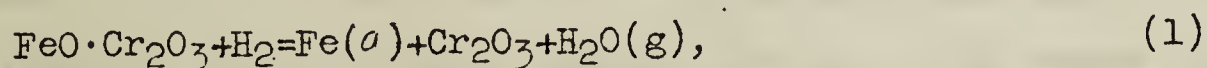
TABLE 12. - Heat content of Fe above 273.2° K.
(cal. per gram atom) (Cont'd.)

| T°, K. | Smooth experimental results | Values from Kelley's equations | Values from composite equation |
|-----------------|-----------------------------------|-----------------------------------|--------------------------------------|
| 1,041 (α) | 6,730 | 6,390 | 6,390 |
| 1,041 (β) | 6,730 | 6,730 | 6,730 |
| 1,073 | 7,040 | 7,040 | 7,040 |
| 1,173 | 8,030 | 8,030 | 8,010 |
| 1,179 (β) | 8,090 | 8,090 | 8,060 |
| 1,179 (γ) | 8,450 | 8,450 | 8,060 |
| 1,273 | 9,240 | 9,240 | 8,970 |
| 1,373 | 10,080 | 10,080 | 9,940 |
| 1,473 | 10,920 | 10,920 | 10,910 |
| 1,573 | 11,760 | 11,760 | 11,880 |
| 1,673 | 12,600 | 12,600 | 12,840 |
| 1,674 (γ) | 12,610 | 12,610 | 12,850 |
| 1,674 (α) | 12,810 | 12,810 | 12,850 |
| 1,773 | 13,800 | 13,800 | 13,810 |
| 1,803 (α) | 14,100 | 14,100 | 14,100 |
| 1,803 (1) | 17,660 | 17,660 | 17,660 |
| 1,873 | 18,240 | 18,230 | 18,230 |

APPENDIX B

DETAILS OF CALCULATIONS FOR THE REACTION, $\text{FeO} \cdot \text{Cr}_2\text{O}_3 + \text{H}_2 = \text{Fe} + \text{Cr}_2\text{O}_3 + \text{H}_2\text{O}$

To illustrate the methods of calculation employed in this report, details for the hydrogen reduction reaction of chromite are recorded. Starting with the reaction



ΔC_p is evaluated from the specific-heat equations of reactants and products (listed in table 2), as

$$\Delta C_p = -5.92 + 5.20 \times 10^{-3} T + 3.883 \times 10^{-5} T^2.$$

The corresponding heat, free energy, and entropy equations are:

$$\Delta H = \Delta H_0 - 5.92T + 2.60 \times 10^{-3} T^2 - 3.883 \times 10^{-5} T^3 \quad (1A)$$

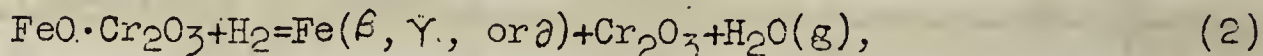
$$\Delta F^0 = \Delta H_0 + 13.63T \log T - 2.60 \times 10^{-3} T^2 - 1.943 \times 10^{-5} T^3 + IT \quad (1B)$$

$$\Delta S = -5.92 - 13.63 \log T + 5.20 \times 10^{-3} T - 1.942 \times 10^{-5} T^2 - I \quad (1C)$$

The quantities ΔH_0 and I are integration constants to be evaluated by the best available means. The latter constant is obtained by substituting $T = 298.2^\circ \text{ K}$. and $\Delta S_{298.2} = 4.89$ (computed from data in table 2) in equation

(1C) and solving for $I = -45.17$. This completes equation (1C), which, in turn, is used to compute $\Delta S_{1041} = 3.35$ at the $\alpha \rightarrow \beta$ iron transition temperature.

Turning now to the similar reaction involving other forms of iron,



there may be written

$$\Delta C_p = -0.38 - 1.18 \times 10^{-3}T + 3.883 \times 10^{-5}T^2$$

$$\Delta H = \Delta H_0 - 0.38T - 0.59 \times 10^{-3}T^2 - 3.883 \times 10^{-5}T^3 \quad (2A)$$

$$\Delta F^0 = \Delta H_0 + 0.875T \log T + 0.59 \times 10^{-3}T^2 - 1.942 \times 10^{-5}T^3 + IT \quad (2B)$$

$$\text{and} \quad \Delta S = -0.38 - 0.875 \log T - 1.18 \times 10^{-3}T - 1.942 \times 10^{-5}T^2 - I \quad (2C)$$

The ΔH_0 and I values, of course, are different from those for reaction (1). To obtain I for reaction (2), there is computed $\Delta S_{1041} = 3.35 + \frac{340}{1041} = 3.68$ (340 cal. being the heat of the $\alpha \rightarrow \beta$ transition in iron). Substitution of $\Delta S_{1041} = 3.68$ and $T = 1,041$ in equation (2C) leads to $I = -8.11$.

ΔH_0 of reaction (2) must be obtained from the experimental hydrogen reduction equilibrium data of table 1. This is done most readily by solving equation (2B) for $\frac{\Delta H_0 + I}{T} = \frac{\Delta H_0}{T} - 8.11$ and substituting $-R \ln K$ for ΔF^0 , thus:

$$\Sigma = -R \ln K - 0.875 \log T - 0.59 \times 10^{-3}T + 1.942 \times 10^{-5}T^2 = \frac{\Delta H_0}{T} - 8.11.$$

If Σ is calculated for each experimental value of K , then ΔH_0 is obtained by noting that $\Sigma + 8.11 = \frac{\Delta H_0}{T}$. This calculation is performed in table 3 for all values of K , and the average, $\Delta H_0 = 15,300$, is adopted. This completes all equations listed under reaction (2).

The heat of reaction (2) at $1,041^\circ \text{K}$. is computed from equation (2A) as $\Delta H_{1041} = 13,890$, which, in turn, gives $\Delta H_{1041} = 13,890 - 340 = 13,550$ for reaction (1). The last figure is substituted in equation (1A) to obtain $\Delta H_0 = 17,270$, and this completes all equations listed under reaction (1).

The other heat and free energy equations of this report were derived similarly, except that the ΔH_0 's were obtained directly by substituting known values of ΔH in the pertinent heat-of-reaction equations.

APPENDIX C

HEAT CONTENT OF NATURAL CHROMITE

The data used for estimating the heat content of a typical natural chromite ore are listed in table 13 together with the heat contents of synthetic chromites of magnesium and iron.

TABLE 13. - Heat contents above 25° C. for chromites
and component oxides

| Temperature, °C. | 1,000° | 1,100° | 1,200° | 1,300° | 1,400° |
|---|--------|--------|--------|--------|--------|
| FeO (cal. per gram mole)... | 13,250 | 14,700 | 16,180 | 17,660 | 19,160 |
| MgO (cal. per gram mole)... | 11,240 | 12,470 | 13,720 | 14,990 | 16,260 |
| Al ₂ O ₃ (cal. per gram mole). | 27,030 | 30,090 | 33,150 | 36,210 | 39,270 |
| Cr ₂ O ₃ (cal. per gram mole). | 28,540 | 31,660 | 34,810 | 37,980 | 41,170 |
| SiO ₂ (cal. per gram mole).. | 15,540 | 17,360 | 19,240 | 21,170 | 23,160 |
| MgO·Cr ₂ O ₃ (cal. per gram mole) | 39,280 | 43,700 | 48,160 | 52,660 | 57,200 |
| FeO·Cr ₂ O ₃ (cal. per gram mole) | 41,790 | 46,360 | 50,990 | 55,640 | 60,330 |
| Natural Benbow chromite (kg. cal per kilogram*) | 210.2 | 233.4 | 256.9 | 280.4 | 304.2 |

*Benbow chromite of composition listed earlier; values computed as 2 per-cent less than the sum of heat contents of component oxides.

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

EFFECTS OF BORON IN STEEL



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REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

EFFECTS OF BORON IN STEEL^{1/}

By R. B. Corbett^{2/} and A. J. Williams^{3/}

INTRODUCTION

This investigation was undertaken to obtain information concerning the effects of boron in steel and its method of addition, so that boron, which is readily obtainable domestically, may be used to relieve the great demand for those scarce, strategic, alloying elements that hitherto have been considered necessary for the successful manufacture of quality steel.

Previous Work

Guillet^{4/} seems to have been the first to predict that boron-bearing steel might have a possible industrial use when, in 1907, he published results of an investigation into the properties of steel containing 0.21 to 1.51 percent boron.

Possibly Walter^{5/} was the first to appreciate the fact that extremely small percentages of boron are effective in improving the properties of a steel. His patent, issued in 1924, claimed steels containing boron within the limits of 0.001 to 0.100 percent; furthermore, the specification disclosed that boron increased the hardenability of steel and refined its grain structure. In 1937, Naton and Piwowsky^{6/} likewise observed that boron increased the hardenability of steel.

Grossman^{7/} was the first to study the actual effects of boron upon the hardenability of steel. On the basis of figure 1, Grossmann stated that

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- ^{1/} The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3816."
 - ^{2/} Assistant metallurgist, Metallurgy of Steel Section, Bureau of Mines, Pittsburgh, Pa.
 - ^{3/} Junior metallurgist, Metallurgy of Steel Section, Bureau of Mines, Pittsburgh, Pa.
 - ^{4/} Guillet, L., Compt. rend., vol. 144, 1907, pp. 1049-1050.
 - ^{5/} Walter, R., Alloy: U. S. Patent 1,519,388, Dec. 16, 1924.
 - ^{6/} Naton, G., and Piwowsky, E., Effect of Boron up to 0.1 Percent on the Mechanical Properties of Cast Steels Containing 0 to 5 Percent Nickel: Archiv Eisenhut., vol. 11, December 1937, pp. 283-286.
 - ^{7/} Grossmann, M. A., Hardenability Calculated from Chemical Composition: Trans. Am. Inst. Min. and Met. Eng., vol. 150, 1942, pp. 227-259.

"Boron is an outstandingly powerful element for increasing hardenability, having its maximum effect when added in the extremely minute amount of 0.0025 percent." The term "multiplying factor," shown on the graph, represents the hardenability conferred by boron alone. For instance, a multiplying factor of 1.4 due to a boron addition of 0.002 percent means that the hardenability of the steel has been increased 1.4 times owing to the boron addition. Unfortunately, the boron percentages plotted are "added" boron and not that actually present in the steel.

Lippert^{8/} recommended boron for use in quenched and tempered steels containing 20 to 60 points of carbon. He discussed the addition of boron to steel and recommended using the boron addition agent, Silcaz.

In 1942, Comstock^{9/} reported the effects of adding three boron-containing "deoxidizers" to five heats of 0.40 percent carbon forging steel. He observed that boron increased the hardenability, but that it coarsened the grain size, especially when added as ferroboration. He also stated that small boron additions gave good ductility and superior toughness with high strength in the case of steel that had been quenched and then drawn at low temperatures. Another paper by Comstock^{10/} described the use of boron plus titanium in heat-treated steel and stated that the treatment of medium-carbon steels with bortam or carbortam promoted uniformity of hardenability.

In 1942, a report by the American Iron and Steel Institute^{11/} dealing with hardenability and mechanical property tests on boron-treated steels stated that the increase in hardenability due to boron was largely independent of the type of alloy added but varied with the type of steel. The report related that the improvement in hardenability was accompanied by an increase in strength in the critical sections and often by an increase in ductility and toughness. In addition, the notched-bar sensitivity was improved in steels used in the as-quenched or slightly tempered condition. Moreover, boron steels that had been normalized were not improved materially.

Tisdale^{12/}, ^{13/}, ^{14/} has advocated the use of boron as a means of increasing the hardenability of steel. According to him, hot shortness found

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- ^{8/} Lippert, T. W., Boron Steel Alloying Agents: Iron Age, vol. 150, Nov. 19, 1942, pp. 41-44.
- ^{9/} Comstock, G. F., Effects of Eight Complex Deoxidizers on Some of 0.40 Percent Carbon Forging Steels: Trans. Am. Inst. Min. and Met. Eng., vol. 150, 1942, pp. 408-420.
- ^{10/} Comstock, G. F., Boron Plus Titanium in Heat-Treated Steels: Metals and Alloys, vol. 17, No. 5, May 1943, pp. 978-983.
- ^{11/} Special Committee, Report on Special Alloy Addition Agents: Am. Iron and Steel Inst., Contributions to Metallurgy of Steel, No. 9, November 1942, 30 pp.
- ^{12/} Tisdale, N. F., Boron - A New Vitamin for Steel and Cast Iron: Metal Progress, vol. 41, March 1942, pp. 330-331.
- ^{13/} Tisdale, N. F., Boron Steels Increasingly Favored: Iron Age, vol. 151, Feb. 4, 1943, pp. 40-44.
- ^{14/} Tisdale, N. F., Boron Found to Be a Very Beneficial Alloying Element: Blast Furnace and Steel Plant, vol. 31, No. 1, January 1943, pp. 93-94.

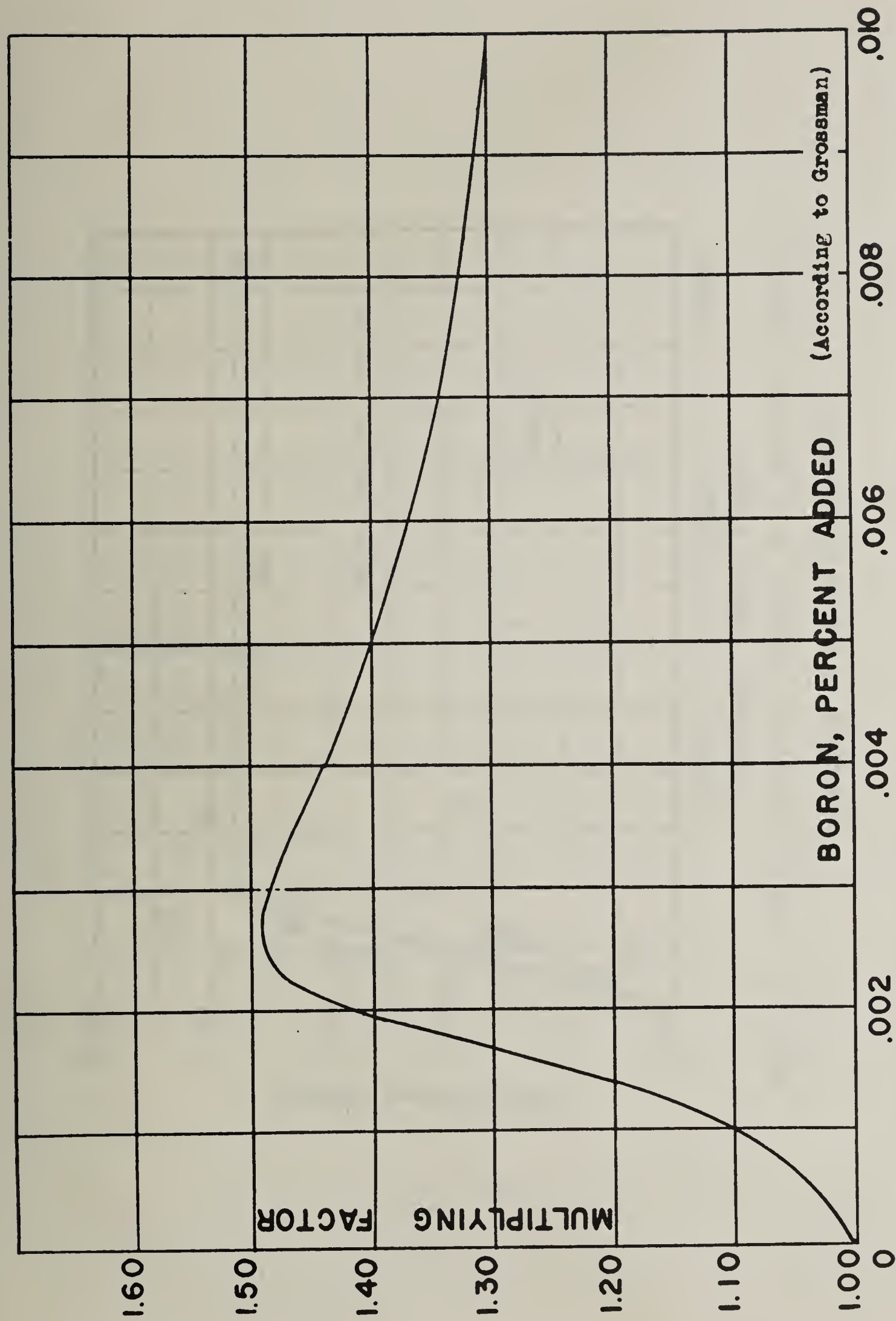


FIG. 1.—MULTIPLYING FACTOR FOR CALCULATION OF EFFECT OF BORON ON HARDENABILITY.

1000



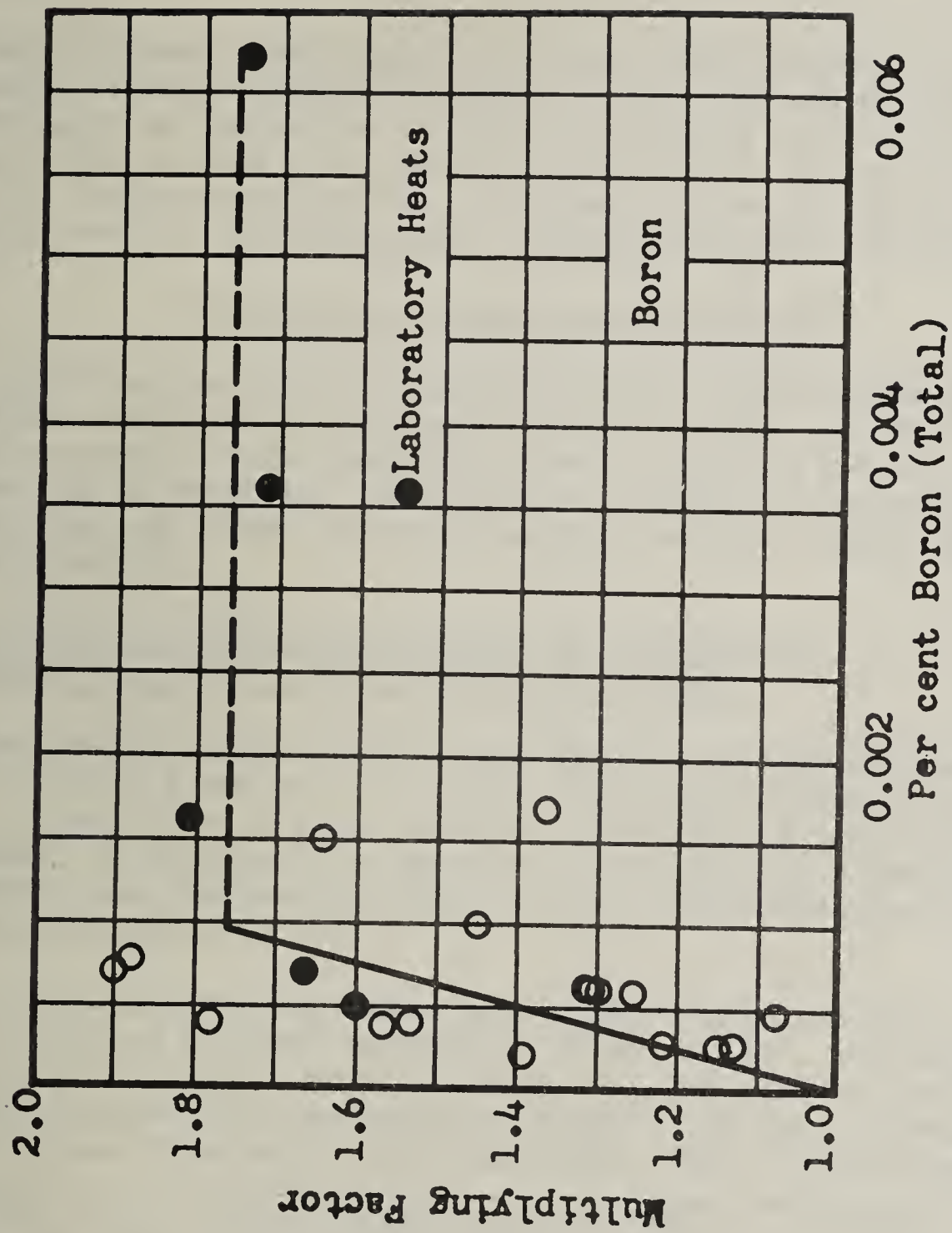


FIG. 2.—MULTIPLYING FACTOR FOR BORON (TOTAL).
(According to Crafts and Lamont)



Y
X
10
9
8
7
6
5
4
3
2
1
0

10
9
8
7
6
5
4
3
2
1
0

10
9
8
7
6
5
4
3
2
1
0

10
9
8
7
6
5
4
3
2
1
0

in boron steels is caused by the formation of an envelope of an iron-carbide, iron-boride solid solution around the grains. He stated that in some steels as much as 0.008 percent boron may be present without hot shortness, but generally less than 0.003 percent was recommended for safe practice.

Schenck^{15/} described the effects of special addition agents in steel, but in most instances he neglected to record the agent used, and in every instance the boron content of the steel was not shown. However, he concluded that improvement in mechanical properties from additive treatment was confined mostly to carbon and low-alloy steels quenched and drawn at 300° to 500° F.

Using Grossmann's principles but their own experimental data, Crafts and Lamont^{16/} found, as shown in figure 2, that the multiplying factor for boron increased in proportion to the boron content up to 1.76 at slightly less than 0.001 percent boron, and that this factor was maintained at that level up to 0.006 percent boron. In figure 2, the open circles represent open-hearth steels; the closed ones, induction-furnace laboratory heats.

Importance of a Hardenability Study

As indicated, neither the hardness nor any other property of a steel is materially improved by treatment with boron if the steel is normalized, annealed, or given a high-temperature draw. The most important effect of the proper use of boron is, therefore, to increase the hardenability of steel that is used in the quenched condition without tempering or with only a slight tempering.

Why It Is Possible to Substitute Boron on the Basis of Hardenability for Other Alloying Elements in Steel

Burns, Moore, and Archer^{17/} found that the surface hardness of carbon and alloy steels of the S. A. E. types is governed primarily by the carbon content, irrespective of alloy content. The depth of hardening upon quenching, however, is dependent on the addition of alloying elements; thus, plain carbon steels are shallow-hardening, whereas alloy steels may be hardened throughout the cross section.

If a steel hardens throughout upon quenching and is then drawn to substantially uniform hardness through the cross section, its hardness, ultimate strength, yield strength, percent elongation, and percent reduction of area are closely related, and its impact strength and fatigue strength may be predicted within reasonably close limits.^{18/}, ^{19/} It should be noted that

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- ^{15/} Schenck, R. B., Special Addition-Agent Steels: Iron Age, vol. 152, No. 16, Oct. 16, 1943, pp. 88-93.
- ^{16/} Crafts, W., and Lamont, J. L., Effect of Some Elements on Hardenability: Metals Technology, T. P. 1657, January 1944, 11 pp.
- ^{17/} Burns, J. L., Moore, T. L., and Archer, R. S., Quantitative Hardenability: Trans. Am. Soc. Metals, vol. 26, No. 1, 1938, pp. 1-36.
- ^{18/} Janitzsky, E. J., and Baeyertz, M., The Marked Similarity in Tensile Properties of Several Heat-Treated S. A. E. Steels: A. S. M. Handbook, 1939, pp. 515-518.
- ^{19/} Patton, W. G., Mechanical Properties of N. E., S. A. E., and Other Hardened Steels: Metal Progress, vol. 43, No. 5, May 1943, pp. 726-733.

because of this interdependence of physical properties, hardenability measurements have been utilized extensively by the American Iron & Steel Institute and others in their development of the national-emergency steels.

Thus, although certain alloys have certain specific effects (such as promoting corrosion resistance, resistance to creep at high temperature, or grain refining), it can be seen that any combination of alloys that will yield the required hardenability probably would serve just as well as any other combination producing the same hardenability. This assumption that steels of equivalent hardenability are interchangeable for many applications indicates that a boron steel of a certain hardenability will be just as serviceable as another steel of similar hardenability.

EXPERIMENTAL PROCEDURE

Making and Shaping the Steels

The 119 steels^{20/} examined in this investigation were made in a 35 kv.-a. high-frequency induction furnace. The basic charge for each heat of steel weighed 17 pounds and consisted of clean boiler punchings of known analysis plus sufficient wash metal so that the carbon could be caught "coming down" by means of an A. C. carbon tester. When the temperature of the bath was proper, 50 percent ferrosilicon was added to deoxidize the metal and to add the silicon necessary to obtain the desired content. Medium-carbon ferromanganese was then added to meet the manganese specification. Any slag present was removed, and the boron addition under study was made to the bare surface of molten steel.

After the boron addition agent had dissolved, the steel was cast into an ingot mold equipped with a hot top. After the ingot was separated from its mold, it was numbered and covered with sand for slow cooling.

When a number of ingots had been collected, they were hammer-forged into 1-1/4-inch-diameter bar stock. During forging, liberal portions of the top and bottom sections of the ingots were hot-cropped for discard.

Boron Addition Agents Used

Table 1 lists the composition of the 16 boron-bearing addition agents used in this investigation. All were obtained from commercial sources except the last three (C, F, and G), which were prepared experimentally.

The alloys silvaz, silcaz, bortam, and carbortam are often referred to as "special deoxidizers" or "special addition agents," as they consist of various combinations of such elements as aluminum, boron, calcium, manganese, silicon, titanium, zirconium, and vanadium. The other boron alloys are principally binary combinations of boron with some other element.

^{20/} The chemical analyses of these steels are given in table 2.

TABLE 1. - Composition of commercial boron-containing agents

| Agents | Designation | Composition, percent (approximate) | | | | | | | | | |
|-------------------------------|---|------------------------------------|----|----|------|-----|------|------|-----|---|------|
| | | B | Ti | V | Zr | Al | Si | Mn | C | Others | Fe |
| Silvaz 3 alloy | Silvaz | 0.5 | 10 | 10 | 6 | 6 | 37 | - | - | - | rem. |
| Silcaz 3 alloy | Silcaz | .5 | 10 | - | 4 | 7 | 37 | - | - | 10 Ca | rem. |
| Bortam | Bortam | 1.7 | 17 | - | - | 14 | 21 | 22 | - | - | rem. |
| Carbortam | Carbortam .. | 1.0 | 16 | - | - | 1.5 | 3 | - | 7 | - | rem. |
| Borosil | Borosil | 3.5 | - | - | - | - | 42 | - | - | - | rem. |
| Titanium-boride | TiB | 13 | 50 | - | - | - | - | - | 14 | - | rem. |
| Ferro-boron | FeB | 10.2 | - | - | - | - | - | - | .70 | - | rem. |
| Manganese-boron alloy | MnB | 20.8 | - | - | - | - | - | rem. | - | - | rem. |
| Boron-carbide | BC | 78 | - | - | - | - | - | - | 21 | - | - |
| Fused boron trioxide glass .. | B ₂ O ₃ | - | - | - | - | - | - | - | .3 | 99 B ₂ O ₃ 100 percent | - |
| Pyrobor | Na ₂ B ₄ O ₇ | - | - | - | - | - | - | - | - | Na ₂ B ₄ O ₇ Cr rem. Ni rem. | - |
| Chromium-boron | CrB | 71.2 | - | - | - | - | - | - | - | - | - |
| Nickel-boron alloy | NiB | 10.7 | - | - | - | - | - | - | - | - | - |
| C | C | 8.0 | - | - | 11.2 | - | - | - | 3.2 | - | rem. |
| F | F | 6.5 | - | - | 14.5 | - | 15.5 | - | 2.8 | - | rem. |
| G | G | 9.8 | - | - | 42.0 | - | - | - | 2.7 | - | rem. |

Methods of Testing Used

The hardenability of the various boron steels was evaluated by application of the Jominy hardenability test in accordance with the standard procedure developed by the Society of Automotive Engineers^{21/} and agreed upon by the American Society for Testing Materials^{22/} and the Steel Standardization Group,^{23/} consisting of representatives from the major steel companies.

The austenitic grain size of the steel at time of quench was determined by comparing the fracture grain size of the martensitic portion of the Jominy bar with a series of standard P-F grain-size standards, whereas the relative cleanliness of the steels was established either metallographically or by application of the Fitterer electrolytic method for extracting inclusion from steels,^{24/}, ^{25/} which was modified somewhat to serve the purpose of this investigation.

Analyzing the Steel Chemically

Chemical analyses^{26/} were made on the fine turnings obtained from the finishing cuts to the Jominy-test specimens. Carbon, manganese, silicon, etc., were determined by the usual chemical procedure, whereas the boron content was obtained by the Quinalizarine method developed by the Youngstown Sheet & Tube Co.^{27/} Analyses were made, also, for phosphorus, sulfur, nickel, copper, molybdenum, chromium, and vanadium, etc., on a number of heats taken at random to establish the presence and percentage variation of these elements, as residuals often influence the hardenability to a great extent. In addition, the total aluminum, titanium, vanadium, and acid-soluble zirconium were determined by Cunningham's methods^{28/} for those steels to which these elements had been introduced by various boron-bearing addition agents.

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- ^{21/} Committee, S. A. E. Standard Procedure Recommended for Testing Hardenability of Steel: S. A. E. Jour., vol. 50, No. 1, January 1942, pp. 15-20.
- ^{22/} Committee, Tentative Method of End-Quench Testing for Hardenability of Steel, A. S. T. M. Designation A255-42T: A. S. T. M. Standards, pt. 1, 1942, pp. 1106-1112.
- ^{23/} Jominy, W. E., Standardization of Hardenability Tests: Metal Progress, vol. 40, No. 6, December 1941, pp. 911-914.
- ^{24/} Fitterer, G. R., Method of Electrolytic Extraction of MnO, MnS, FeS, and SiO₂ Inclusions from Plain Carbon Steels: Mining and Metallurgical Investigations, Coop. Bull. 51, Mining and Metallurgical Advisory Boards, 1931, 15 pp. Also Trans. Am. Inst. Min. and Met. Eng., vol. 95, 1931, pp. 196-208.
- ^{25/} Fitterer, G. R., Sockman, B. E., Krockenberger, K. A., Meneilly, R. B., Marshall, E. W., and Eckel, J. F., The Development of an Electrolytic Method for the Determination of Inclusions in Plain Carbon Steels: Bureau of Mines Rept. of Investigations 3205, May 1933, 67 pp.
- ^{26/} The chemical analyses of the steels examined herein are given in table 2.
- ^{27/} Rudolph, G. A., and Flickinger, L. C., Colorimetric Determination of Boron in Steel, Using the Quinalizarine Reaction: Steel, vol. 112, No. 14, Apr. 5, 1943, p. 114.
- ^{28/} Cunningham, T. R., Private communication.

RESULTS OF THE INVESTIGATION

General Observations

Making and shaping of the boron steels presented no particular difficulty. Although previous reports indicated that 0.007 percent boron added to steel produced hot shortness,^{29/}, ^{30/}, ^{31/} heat No. 70, containing 0.017 percent total boron was forged without difficulty. However, heat No. 102, containing 0.024 percent total boron, was hot short, indicating that the change to hot shortness occurred somewhere between 0.017 and 0.024 percent total boron. Similarly, the observation that boron did not coarsen the grain size of the steel is contrary to that of Tisdale^{32/} and Comstock.^{33/} In addition, it was found that the boron steels were of commercial cleanliness, indicating that none of the boron addition agents were detrimental to the production of quality steel.

Influence of Boron on the Hardenability of SteelCalculation of the Multiplying Factor for Boron

From the grain size and chemical composition of a steel, its hardenability may be calculated with an accuracy of 10 to 15 percent by use of Grossmann's method,^{34/} which is based upon the concept that a pure iron-carbon alloy has a certain hardenability, and that each additional element is represented by a multiplying factor by which the base hardenability is multiplied, the total hardenability of the steel being the product of all the factors, with a proper correction for grain size. Of far greater importance, however, is that fact that if the hardenability, grain size, and multiplying factors for the various elements, with the exception of boron, are known, it is possible to calculate the multiplying factor due to boron alone and thus show the effect of boron upon the hardenability of the steel.

In calculating the multiplying factor for boron, Grossmann's principles of calculation were used along with his curves of multiplying factors for the various elements except silicon and manganese, for which the curves of Crafts and Lamont were considered more applicable.

As Grossmann has stressed the importance of accounting for the presence of residual alloying elements when calculating the hardenability of a steel, a number of the boron steels were analyzed completely chemically, the average residuals being:

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- ^{29/} Work cited in footnote 14.
^{30/} Work cited in footnote 15.
^{31/} Anonymous, Boron in Steels; a Composite of Abstracts: Metals and Alloys, vol. 17, June 1943, p. 1228.
^{32/} Work cited in footnote 14.
^{33/} Work cited in footnote 10.
^{34/} Work cited in footnote 8.

| | Percent |
|----------|---------|
| S | 0.030 |
| P | .015 |
| Cr | .020 |
| Mo | .005 |
| Al | .000 |
| V | .000 |
| W | .000 |

The presence of these elements introduced, therefore, a general multiplying factor of 1.07 into the hardenability calculations.

By application of Grossmann's method, it was possible to calculate the effect on hardenability due to boron alone. For example, a boron-bearing steel with a specific carbon content and grain size has a certain base hardenability that must be multiplied by a M. F. (multiplying factor) for its manganese, silicon, and residual contents to obtain a product (such as 1.12 inches) that is the ideal critical (bar diameter of the steel and that represents the hardenability of the steel, assuming the absence of boron. The hardenability of the steel, including the effect due to boron, however, is known as a result of the Jominy hardenability test. Fortunately, a correlation exists between the Jominy and Grossmann hardenability methods,^{35/} so that it is possible to express one in terms of the other. Suppose, therefore, that the Jominy test, upon conversion to Grossmann units, indicated that the steel under discussion had an ideal critical diameter of 1.60 inches; then, as the ideal critical diameter was but 1.12 inches when the absence of boron was assumed, the multiplying factor due to the presence of the boron is 1.60 inches divided by 1.12 inches, or 1.43.

In a number of the boron steels investigated, small percentages of vanadium, aluminum, zirconium, and titanium were introduced unavoidably, because they were chemical components of the boron addition agents under study. As these elements affect the hardenability, their presence had to be determined chemically and their effect on the hardenability taken into account by use of their respective multiplying factors, which may be found in the work of Crafts and Lamont.^{36/}, ^{37/} Accordingly, it was found that the percentage of titanium introduced by the bortam, carbortam, and titanium-boride additions was so small as to have little influence on the hardenability. However, sufficient titanium was introduced by use of silvaz and silcaz to affect the hardenability, as was also the vanadium introduced by the silvaz addition. (For percentage of titanium and vanadium introduced and their respective multiplying factors, refer to table 3.) Similarly, the percentage of zirconium introduced by silvaz, silcaz, and the zirconium-boron alloys (C, F, and G) and the percentages of aluminum introduced by silvaz, silcaz, and bortam were so small that their presence had no appreciable influence on hardenability.

^{35/} Work cited in footnote 8.

^{36/} Work cited in footnote 17.

^{37/} Crafts, W., and Lamont, J. L., The Effect of Silicon on Hardenability: Trans. Am. Inst. Min. and Met. Eng., vol. 154, 1943, pp. 386-394.

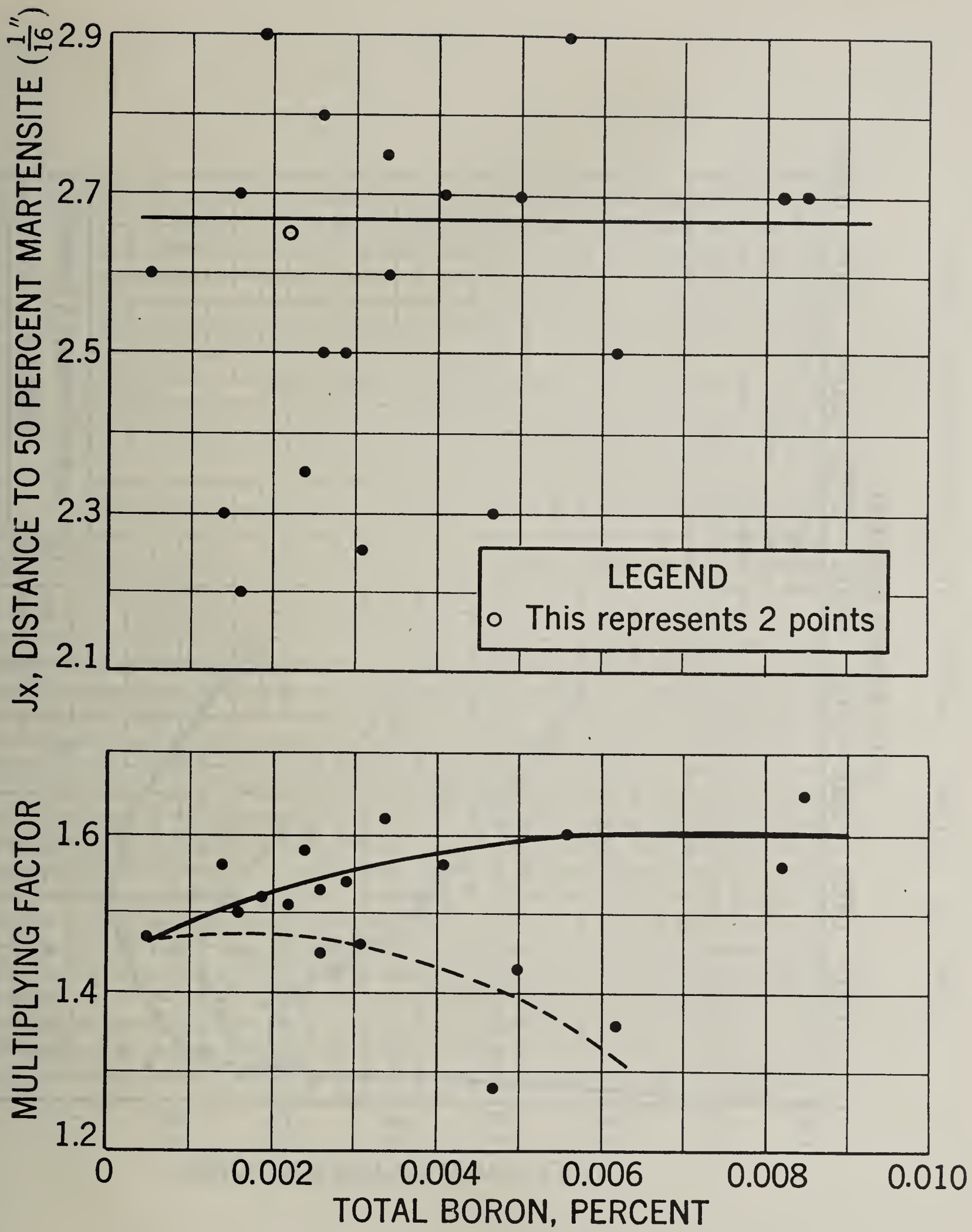


Figure 3 .—Comparison of Jx and M.F. for boron steels of similar analyses.

FIGURE 1. EFFECT OF TOTAL BORON ON THE GROWTH OF WHEAT

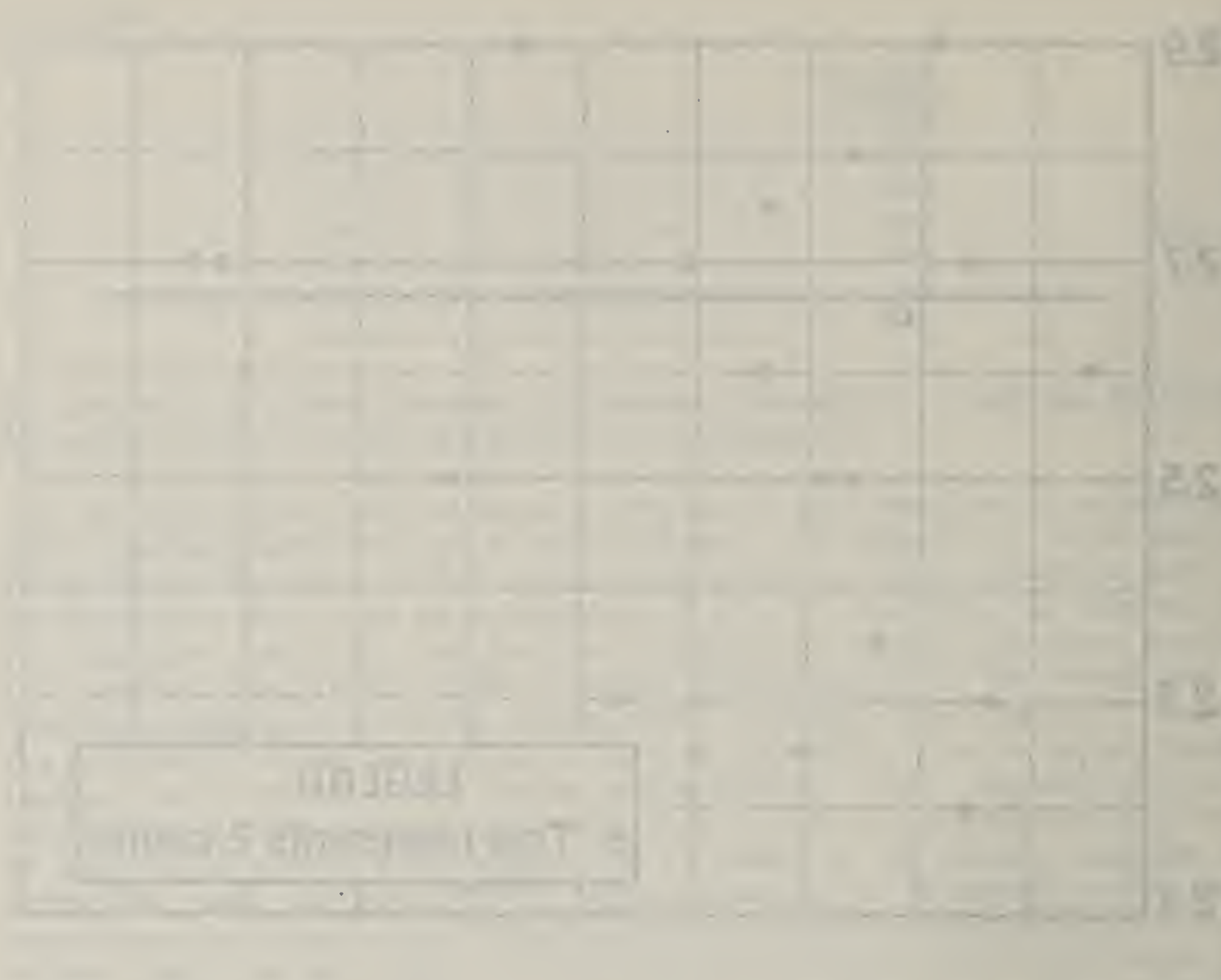


FIGURE 2. EFFECT OF TOTAL BORON ON THE GROWTH OF WHEAT



Source: U.S. Department of Agriculture, Agricultural Research Service, Soil Conservation Service, and National Bureau of Plant Industry, Washington, D.C.

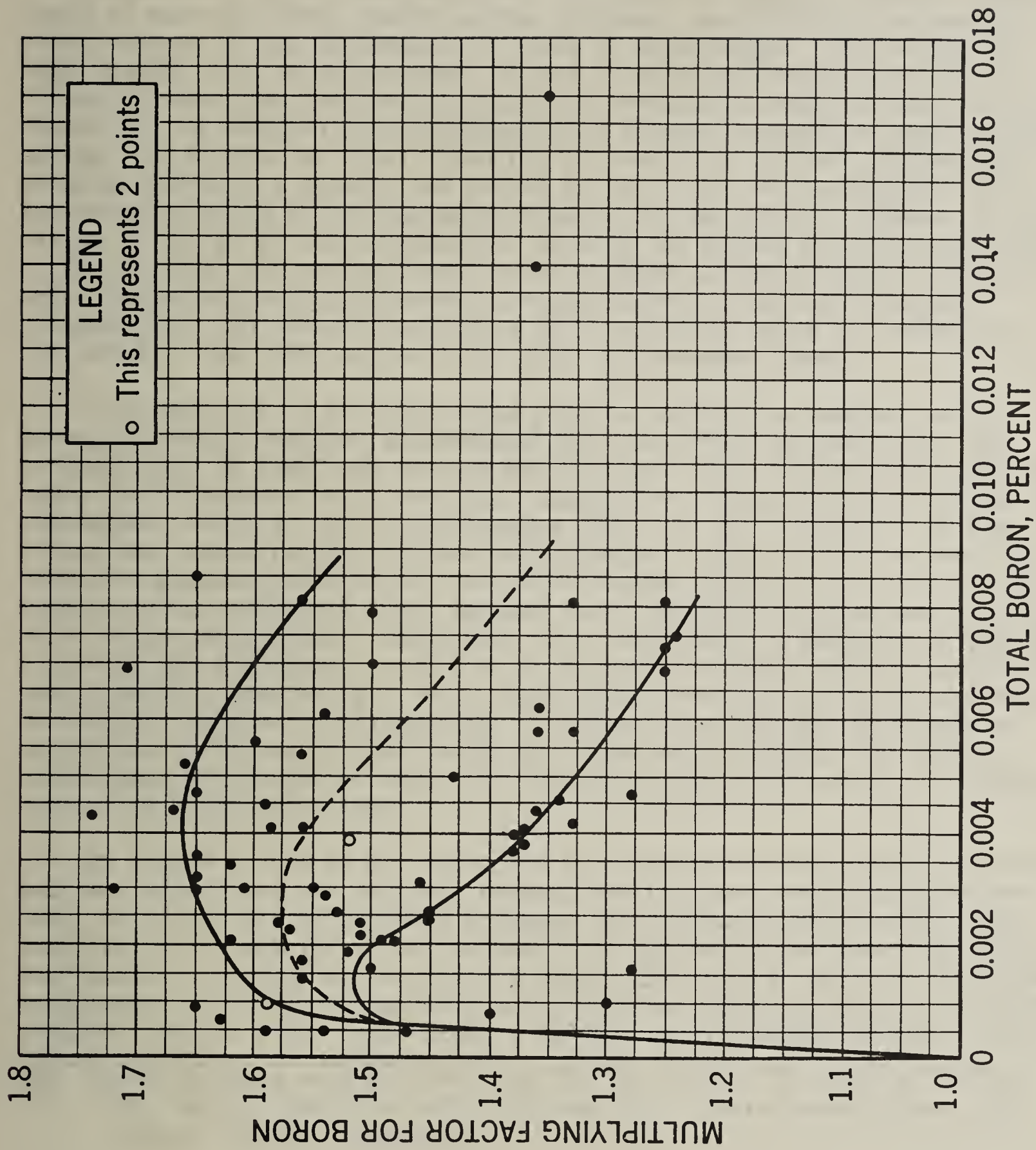
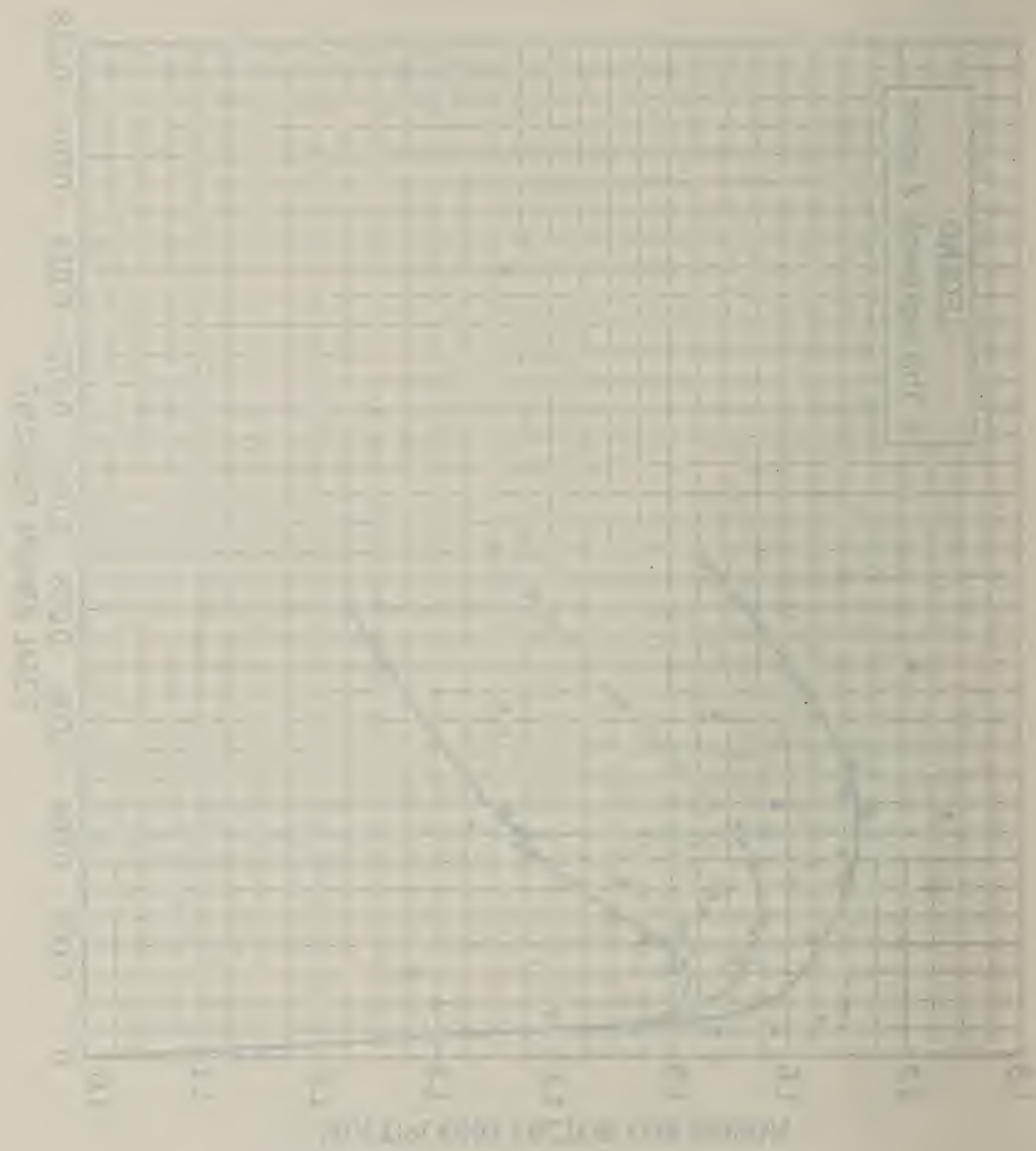


Figure 4 .—Effect of boron on the hardenability of steel.



Information Obtained as a Result of Calculating
the Multiplying Factor for Boron

Originally, it was believed that if steels of similar chemical analyses could be made and their Jominy curves compared, the effect of increasing boron content on the hardenability could be established. The fallacy of this thought soon became evident, as may be seen from the upper curve of figure 3, where the J values (distance in sixteenths from quenched face of Jominy bar to position of occurrence of 50 percent martensite) were plotted against the percent of total boron for 21 steels of similar analyses.^{38/} From the curve of J values, the effect of boron upon the hardenability is not evident, owing to the random scattering of the points. However, calculation of the M. F. due to boron for each of the steels and plotting of these M. F.'s against the percent total boron yielded the lower curve of figure 3, which indicates that an increase in boron increases the hardenability. Incidentally, the possible existence of a second or sub M. F. curve, as indicated by the lower dotted line, will be discussed later.

When the M. F.'s for boron were plotted against the percent total boron, the graph of figure 4 was obtained, and the effect of boron upon the hardenability of steel was thereby established. The straight-line portion below 0.0006 percent total boron was taken from a similar graph of Crafts and Lamont (see fig. 2), who calculated the M. F. for a total of 16 heats within the narrow region of 0 to 0.0010 percent total boron. To the right of 0.0006 percent total boron, the curve became a region, owing to the fact that for each individual boron content there existed a maximum and a minimum M. F. value; accordingly, therefore, there were drawn a maximum, an average (dotted), and a minimum curve of M. F. values. As noted above, this tendency towards a scattering of M. F. values was found for a series of steels of similar analyses. Incidentally, it should be noted that Grossmann's method has a reputed accuracy of 10 to 15 percent, and that the maximum and minimum M F curves of figure 4, when compared to the middle or average curve, are within this limit.

In figure 4, the M. F.'s of boron for steels to which silcaz and silvaz had been added were not plotted, because their values were generally very low. As silvaz and silcaz both increase the hardenability of steel, this observation is believed to be the result of the use of an incorrect multiplying factor for titanium. Crafts and Lamont,^{39/} whose M. F.'s for titanium were used in this paper, maintain that titanium greatly increases the hardenability. On the other hand, Kramer, Hafner, and Toleman^{40/} contend just the

^{38/} These 21 heats were Nos. 40, 56, 71, 78, 79, 80, 81, 82, 83, 84, 85, 88, 90, 94, 96, 100, 104, 105, 110, and 115. Their compositions fall within the following range:

| C | Mn | Si |
|-------------------|-------------------|-------------------|
| 0.56/0.65 percent | 0.52/0.63 percent | 0.20/0.35 percent |

^{39/} Work cited in footnote 17.

^{40/} Kramer, J. R., Hafner, R. H., and Toleman, S. L., Effect of Sixteen Alloying Elements on Hardenability of Steel: Metal Technol., Tech. Pub. 1636, September 1943, 11 pp.

opposite. Indication that titanium does decrease the hardenability is shown by the fact that the steels having low M. F. values for boron were those containing titanium introduced through use of silvaz and silcaz. Similarly, some steels^{41/} to which this element had been introduced by means of bortam, carbortam, or titanium-boride also had low M. F.'s for boron.

Figure 4, showing the effect of boron on the hardenability of steel, cannot be compared with the results of previous investigators. In figure 1, Grossmann shows the M. F. of boron plotted against the percent added boron, as no satisfactory method was available for determining the actual boron content of the steel; furthermore, the data from which he constructed his curve were rather limited. As the curve of Crafts and Lamont (see fig. 2) is considered correct up to 0.0006 percent total boron, it agrees with figure 4; but at higher percentages of boron, their curve was based on only five points. However, the curve of figure 4 does agree with the often-reported observation that a boron content in the region of 0.0025 percent seems to exert the greatest influence on the hardenability, and that the hardenability decreases with further increase in boron.

It is important to note that figure 4 shows the great influence of minute amounts of boron on the hardenability. For instance, the presence of 0.003 percent total boron in steel results in the following M. F.'s:

| Maximum | Average | Minimum |
|---------|---------|---------|
| 1.65 | 1.58 | 1.43 |

which means that the hardenability of the steel has been increased 43 to 65 percent by the 0.003 percent boron content. Calculation on the basis of an average M. F. of 1.58 will reveal that 0.003 percent boron in steel has an effect on the hardenability equal to a silicon content of 0.87 percent, a nickel content of 0.79 percent, a chromium content of 0.27 percent, a manganese content of 0.12 percent, or a molybdenum content of 0.23 percent. Stated otherwise, 0.003 percent boron exerts the same influence on the hardenability as 263 times as much nickel, 90 times as much chromium, 40 times as much manganese, or 77 times as much molybdenum.

Grossmann has pointed out that the effect of an element on the hardenability is not additive but acts through the principle of multiplication; in other words, if two elements are equally effective on the hardenability, a greater hardenability will be obtained by using, for example, 0.5 percent of each rather than by using 1.0 percent of either of them alone. Accordingly, therefore, if a given steel contains any of the above elements when the boron is added, the boron addition may be used to save even greater amounts of one or more of these elements. For example, if a steel contains 0.40 percent molybdenum, the molybdenum content may be reduced to 0.11 percent by the boron addition without change in the hardenability. Similarly, if a steel contains 1.00 percent chromium, the chromium content may be reduced to 0.46 percent by introducing 0.003 percent boron, and the hardenability will remain unchanged. However, since steel making still has not

^{41/} These heats are: Bortam, 49, 59, 111; carbortam, 50, 60; titanium-boride, 29, 30, 31, 32.

been developed into an exact science, the above theoretical substitutions should serve merely as valuable guides for the actual substitutions, which should be determined by practice.

Comparison of the Various Boron Addition Agents

On the Basis of Their Efficiency

The 16 boron addition agents listed in table 1 were added to plain carbon steel, and their efficiencies were calculated. (Refer to table 2 for chemical composition of each steel, the boron agent added, and the resulting efficiency of the addition agent.) In this discussion, efficiency is used as a quantitative measure of recovery. It equals percent boron recovered according to chemical analysis, divided by percent boron added to the steel, multiplied by 100.

Observations on the relative efficiencies of the boron addition agents added to melts made in the induction furnace should apply also to heats made in other types of melting furnaces. Actually, the various boron addition agents should show greater efficiencies when they are added to open hearth or electric furnace melts, because induction furnace melting, contrary to the general opinion, is oxidizing in character. In the induction furnace used for these experiments the action of the electromagnetic forces on the molten metal caused rapid stirring of the bath; thus, a fresh metal surface was constantly subjected to the oxidizing action of the slag and atmosphere. Incidentally, Comstock,^{42/} who added bortam and carbortam to induction furnace melts, substantiated this statement by noting that "in large commercial heats, which are less oxidized in melting, additions about half as large are generally effective."

Early in the investigation it was established that the method of adding the boron agent to the melt was not critical if the bath had been properly killed and cleared of slag previous to introduction of the boron agent. In this phase of the work, the following methods of addition were studied: (a) The boron agent was dropped on the slag-free metal surface or (b) placed in an envelope and plunged into the bath by means of an iron wire or (c) sealed in the end of an iron rod and then plunged into the bath. Consequently, method (a) was used throughout the experimental work, except as noted in the data of table 2. Table 2 also gives the efficiencies of the various boron agents when added to steel. For convenience they may be listed as follows:

^{42/} Work cited in footnote 11.

| Addition agent | No. of heats | Range of efficiencies | Average efficiency |
|-----------------------------|--------------|-----------------------|--------------------|
| Ferro-boron | 29 | 43/49.3-130.0 | 79.5 |
| Titanium-boride | 13 | 43/16.7-94.5 | 56.0 |
| Silcaz | 7 | 72.0-120.0 | 98.9 |
| Manganese boron alloy | 7 | 66.2-87.7 | 78.0 |
| Chromium-boron | 6 | 48.4-100.5 | 72.5 |
| Borosil | 5 | 84.7-139.0 | 88.7 |
| Bortam | 5 | 21.3-55.7 | 38.5 |
| Boron-carbide | 4 | 80.7-119.0 | 98.0 |
| Silvaz | 4 | 73.0-106.0 | 88.0 |
| Carbortam | 4 | 36.2-88.5 | 61.1 |
| Nickel-boron alloy | 3 | 76.7-98.5 | 88.6 |
| C | 2 | 49.0-50.0 | 49.5 |
| F | 1 | | 58.1 |
| G | 1 | | 32.0 |

The spread between the maximum and minimum recoveries for a particular boron agent was too great to warrant classifying the agents according to their relative efficiencies. The reason for this spread was that the various addition agents were not homogeneous with respect to chemical composition; furthermore, the amount of addition per heat was small.

From the above, it is important to note that silcaz and silvaz, which contain elements other than boron for the express purpose of protecting the boron from oxidation while these agents dissolve in the steel, do have relatively high efficiencies. However, carbortam, and especially bortam, which also contain such "protecting" elements, show low efficiencies.

Further study of table 2 will reveal, also, that the efficiencies of the various boron addition agents were not affected by either the percentages of total boron, carbon, or silicon of the steel. This fact was established by plotting the percent efficiency against these three variables.

Unfortunately it was not possible to check the efficiencies of these various boron addition agents by reference to other publications except in the case of ferro-boron, for which Gillett and Mack^{44/} reported a recovery of 57 to 129 percent when they added it in the arc furnace. Also, Wasmuht^{45/} obtained a recovery of 70 percent on addition of 20 percent ferro-boron to induction-furnace heats of steel; whereas Cronelius^{46/} reported a recovery of 75 to 80 percent under similar conditions.

^{43/} Efficiencies over 100 percent probably are due to homogeneity of the boron addition agent with respect to boron content.

^{44/} Gillett, H. W., and Mack, E. L., Experimental Production of Alloy Steels: Bureau of Mines Bull. 199, 1922, 81 pp.

^{45/} Wasmuht, R., Iron-boron Alloys and 18-8 Steels Plus Boron; Their Hardenability and Precipitation Hardening: Archiv Eisenhüt., vol. 5, 1931-32, p. 261.

^{46/} Cornelius, H., The Hardening on Tempering of Austenitic Chromium Nickel Steels Containing Boron: Arch Eisenhüt., vol. 12, April 1939, pp. 499-505.

TABLE 2. - Experimental data

| Heat No. | Chemical analysis, percent | | | | | | Boron addition agent | | Ingot weight, lb. | Efficiency of addition ^{1/} | Percent soluble B. is of T.B. ^{2/} | Grain size | J _x ^{3/} | M. F. due to boron ^{4/} |
|----------|----------------------------|------|------|---------|-----------|---------|---|---------------|-------------------|--------------------------------------|---|------------|------------------------------|----------------------------------|
| | C | Mn | Si | Soluble | Insoluble | Total | Designation | Percent added | | | | | | |
| 1.. | 0.56 | 1.72 | 0.59 | 0.0007 | 0.0074 | 0.0081 | MnB | 0.0100 | 5 | - | 8.6 | - | - | - |
| 2.. | 2.47 | 1.69 | 1.78 | .0000 | .0008 | .0008 | MnB | .0010 | 5 | - | 0 | - | - | - |
| 3.. | 1.52 | 1.13 | .80 | .0000 | .0000 | .0000 | None | .0000 | 5 | - | 0 | - | - | - |
| 4.. | 1.08 | .93 | .81 | .0000 | .0012 | .0012 | MnB | .0020 | 5 | - | 0 | - | - | - |
| 5.. | .83 | 1.08 | .85 | .0002 | .0033 | .0035 | MnB | .0050 | 5 | - | 5.7 | - | - | - |
| 85/ | .52 | 1.73 | .77 | .0013 | .0068 | .0081 | FeB | .0050 | 5 | - | 16.0 | 8 | 13 | 1.25 |
| 9.. | .36 | .95 | .35 | .0013 | .0028 | .0041 | 6/FeB | .0050 | 15 | - | 31.7 | 8 | - | - |
| 10.. | 1.17 | 1.25 | .38 | .0010 | .0054 | .0064 | 7/FeB | .0050 | 15 | - | 15.6 | 8 | - | - |
| 11.. | .98 | 1.09 | .35 | .0000 | .0025 | .0025 | 6/FeB | .0025 | 15 | - | 0 | 8 | - | - |
| 12.. | .97 | 1.05 | .44 | .0018 | .0088 | .0106 | 6/FeB | .0100 | 15 | - | 17.0 | 8 | - | - |
| 13.. | 1.62 | 1.22 | .45 | .0002 | .0081 | .0083 | 6/BC | .0050 | 15 | - | 2.4 | 8 | - | - |
| 14.. | 1.11 | 1.38 | .32 | .0006 | .0080 | .0086 | BC | .0082 | 14.5 | 101.2 | 7.0 | 8 | - | - |
| 165/ | 1.50 | 1.51 | .35 | .0003 | .0036 | .0039 | 6/MnB | .0050 | 12.7 | 66.2 | 7.7 | 6 | - | - |
| 17.. | 1.30 | 1.44 | .34 | .0002 | .0046 | .0048 | MnB | .0050 | 14.0 | 87.7 | 6.4 | 6 | - | - |
| 18.. | 1.28 | 1.46 | .34 | .0002 | .0044 | .0046 | 7/MnB | .0050 | 14.1 | 86.0 | 4.4 | 8 | - | - |
| 19.. | .99 | 1.38 | .33 | .0005 | .0046 | .0051 | CrB | .0050 | 14.8 | 100.5 | 9.8 | 7 | - | - |
| 20.. | 1.31 | 1.45 | .34 | .0004 | .0040 | .0044 | 6/CrB | .0050 | 14.4 | 84.6 | 9.1 | 6 | - | - |
| 21.. | 1.09 | 1.47 | .34 | .0003 | .0048 | .0051 | Na ₂ B ₄ O ₇ | 10 gr. | 13.1 | - | 5.9 | 8 | - | - |
| 22.. | 1.18 | 1.43 | .34 | .0003 | .0038 | .0041 | Na ₂ B ₄ O ₇ | 5 gr. | 13.7 | - | 7.3 | 8 | - | - |
| 23.. | .86 | 1.40 | .34 | .0003 | .0120 | .0123 | B ₂ O ₃ | 10 gr. | 13.7 | - | 2.4 | 9 | - | - |
| 24.. | 1.67 | 1.39 | .34 | .0000 | .0025 | .0025 | TiB | 0.0050 | 13.7 | 45.7 | 0 | 8 | - | - |
| 25.. | .99 | 1.65 | .40 | .0002 | .0025 | .0027 | 6/TiB | .0050 | 11.6 | 41.8 | 7.4 | 9 | - | - |
| 26.. | 1.56 | 1.49 | .38 | .0000 | .0037 | .0037 | TiB | .0050 | 12.8 | 63.2 | 0 | 8 | - | - |
| 27.. | 1.54 | 1.64 | .38 | .0001 | .0052 | .0053 | 6/TiB | .0050 | 10.4 | 73.6 | 1.9 | 8 | - | - |
| 28.. | .73 | 1.26 | .19 | .0003 | .0020 | .0023 | TiB | .0020 | 12.3 | 94.5 | 13.0 | 8 | - | - |
| 29.. | .72 | 1.30 | .19 | .0003 | .0029 | .0032 | TiB | .0040 | 14.0 | 74.7 | 9.4 | 8 | 5.0 | 1.09 |
| 30.. | .60 | .84 | .25 | .0013 | .0026 | .0039 | TiB | .0060 | 15.0 | 65.0 | 33.3 | 8 | 3.0 | 1.22 |
| 31.. | .61 | 1.03 | .35 | .0020 | .0055 | .0075 | TiB | .0080 | 11.75 | 73.5 | 26.7 | 8 | 3.6 | 1.08 |
| 32.. | .68 | .97 | .33 | .0008 | .0044 | .0052 | TiB | .0100 | 13.75 | 47.6 | 15.4 | 8 | 2.8 | .94 |
| 33.. | .34 | .95 | .34 | .0008 | .0013 | .0021 | FeB | .0010 | 9.25 | 130.0 | 38.1 | 7 | 3.8 | 1.49 |
| 34.. | .34 | .75 | .24 | .0008 | .0013 | .0021 | FeB | .0020 | 12.6 | 88.3 | 38.1 | 8 | 2.5 | 1.62 |
| 35.. | .48 | .70 | .22 | .0006 | .0024 | .0030 | FeB | .0030 | 11.5 | 76.7 | 20.0 | 8 | 2.8 | 1.55 |
| 36.. | .21 | .61 | .17 | .0022 | .0020 | .0042 | FeB | .0050 | 14.5 | 81.3 | 52.4 | 8 | 8/ | - |
| 37.. | .18 | .65 | .28 | .0029 | .0029 | .0058 | FeB | .0070 | 13.6 | 75.3 | 50.0 | 8 | 8/ | - |
| 38.. | .37 | .62 | .21 | .0023 | .0031 | .0054 | FeB | .0090 | 12.5 | 50.0 | 42.6 | 8 | 1.8 | 1.56 |
| 39.. | .53 | .63 | .27 | .0008 | .0017 | .0025 | Na ₂ B ₄ O ₇ | 2 gr. | 14.0 | - | 32.0 | 8 | 2.5 | 1.45 |
| 40.. | .63 | .63 | .24 | .0014 | .0048 | .0062 | Na ₂ B ₄ O ₇ | 4 gr. | 13.0 | - | 22.6 | 8 | 2.5 | 1.36 |
| 41.. | .50 | .64 | .25 | .0009 | .0030 | .0039 | B ₂ O ₃ | 2 gr. | 13.5 | - | 23.0 | 8 | 2.6 | 1.52 |
| 42.. | .47 | .66 | .23 | .0013 | .0048 | .0061 | B ₂ O ₃ | 4 gr. | 13.5 | - | 21.3 | 8 | 2.5 | 1.54 |
| 43.. | .39 | .67 | .23 | .0002 | .0003 | .0005 | FeB | 0.0005 | 15.0 | 100.0 | 40.0 | 7.5 | 2.5 | 1.59 |
| 44.. | .48 | .67 | .24 | .0002 | .0006 | .0008 | FeB | .0010 | 13.25 | 70.7 | 25.0 | 7 | 2.6 | 1.40 |
| 45.. | .41 | .68 | .22 | .0016 | .0008 | .0024 | FeB | .0020 | 14.25 | 114.0 | 66.7 | 5 | 3.5 | 1.51 |
| 46.. | .38 | .59 | .19 | .0008 | .0024 | .0032 | FeB | .0050 | 14.75 | 62.9 | 25.0 | 8.5 | 1.75 | 1.65 |
| 47.. | .47 | .63 | .19 | .0015 | .0030 | .0045 | FeB | .0070 | 16.0 | 68.6 | 33.3 | 8 | 2.4 | 1.59 |
| 48.. | .57 | .67 | .69 | - | - | 2/.0051 | Silcaz | .0050 | 12.9 | 87.5 | - | 8.5 | 3.4 | .98 |
| 49.. | .49 | .67 | .31 | .0003 | .0018 | .0021 | Bortam | .0050 | 14.1 | 39.5 | 14.3 | 8 | 2.4 | 1.40 |
| 50.. | .60 | .67 | .23 | .0018 | .0018 | .0036 | Carbortam | .0050 | 13.25 | 63.6 | 50.0 | 8 | 2.3 | 1.27 |
| 51.. | .65 | .68 | .35 | .0009 | .0066 | .0075 | Borosil | .0050 | 13.1 | 139.0 | 12.0 | 8 | 2.7 | 1.24 |
| 52.. | .73 | .90 | .28 | .0007 | .0044 | .0051 | CrB | .0050 | 7.1 | 48.4 | 13.7 | 8 | - | - |
| 53.. | .48 | .62 | .24 | .0010 | .0029 | .0039 | MnB | .0050 | 15.6 | 81.3 | 25.6 | 8 | 2.3 | 1.52 |
| 54.. | .45 | .64 | .54 | - | - | 2/.0040 | Silvaz | .0050 | 14.6 | 78.0 | - | 8 | 3.7 | 1.04 |
| 55.. | .57 | .64 | .23 | .0009 | .0037 | .0046 | NiB | .0058 | 14.5 | 76.7 | 19.6 | 8 | 2.25 | 1.34 |
| 56.. | .65 | .63 | .24 | .0011 | .0036 | .0047 | FeB | .0050 | 10.5 | 65.8 | 23.4 | 8 | 2.3 | 1.28 |
| 57.. | .47 | .63 | .33 | - | - | 2/.0053 | Silvaz | .0050 | 15.0 | 106.0 | - | 8 | 3.2 | 1.04 |
| 58.. | .52 | .60 | .36 | - | - | 2/.0052 | Silcaz | .0050 | 14.5 | 100.0 | - | 9 | 2.9 | 1.13 |
| 59.. | .75 | .71 | .26 | .0008 | .0023 | .0031 | Bortam | .0050 | 12.0 | 49.6 | 25.8 | 8 | 1.8 | .95 |
| 60.. | .67 | .63 | .10 | .0008 | .0009 | .0017 | Carbortam | .0050 | 16.0 | 36.2 | 47.0 | 8 | 1.8 | 1.21 |
| 61.. | .55 | .62 | .25 | .0014 | .0027 | .0041 | CrB | .0050 | 10.5 | 57.3 | 34.1 | 8 | 2.2 | 1.37 |
| 62.. | .36 | .49 | .15 | .0025 | .0018 | .0043 | Borosil | .0050 | 14.75 | 84.7 | 58.2 | 8 | 1.4 | 1.74 |
| 63.. | .42 | .65 | .22 | .0007 | .0029 | .0036 | MnB | .0050 | 15.0 | 72.0 | 19.4 | 8 | 2.5 | 1.65 |
| 64.. | .58 | .66 | .22 | .0009 | .0060 | .0069 | BC | .0080 | 14.0 | 80.7 | 13.0 | 8 | 2.0 | 1.25 |
| 65.. | .43 | .65 | .39 | - | - | 2/.0022 | Silcaz | .0025 | 15.0 | 88.0 | - | 8.5 | 1.25 | .96 |
| 66.. | .53 | .58 | .19 | .0018 | .0034 | .0052 | B ₂ O ₃ | 5 gr. | 13.4 | - | 34.6 | 8 | 2.6 | 1.66 |
| 67.. | .52 | .63 | .23 | .0015 | .0055 | .0070 | FeB | 0.0120 | 16.0 | 62.2 | 21.3 | 8 | 2.5 | 1.50 |

See footnotes on page 14.

TABLE 2. - Experimental data (Cont'd.)

| Heat No. | Chemical analysis, percent | | | | | | Boron addition agent | | Ingot weight, lb. | Efficiency of addition ^{1/} | Percent soluble B. is of T.B. ^{2/} | Grain size | J _x ^{3/} | M. F. due to boron ^{4/} |
|----------|----------------------------|------|------|---------|-----------|---------|---|---------------|-------------------|--------------------------------------|---|------------|------------------------------|----------------------------------|
| | C | Mn | Si | Boron | | Total | Designation | Percent added | | | | | | |
| | | | | Soluble | Insoluble | | | | | | | | | |
| 68.. | 0.64 | 0.64 | 0.21 | 0.0004 | 0.0077 | 0.0081 | FeB | 0.0160 | 14.6 | 49.3 | 4.9 | 8 | 2.4 | 1.33 |
| 69.. | .58 | .70 | .22 | .0030 | .0110 | .0140 | FeB | .0170 | 14.3 | 78.6 | 22.8 | 8 | 2.6 | 1.36 |
| 70.. | .56 | .65 | .21 | .0050 | .0120 | .0170 | FeB | .0200 | 12.6 | 71.5 | 29.4 | 7 | 2.6 | 1.35 |
| 71.. | .59 | .52 | .21 | .0006 | .0008 | .0014 | FeB | .0020 | 13.6 | 63.5 | 43.0 | 8 | 2.3 | 1.56 |
| 72.. | .52 | .66 | .25 | .0005 | .0016 | .0021 | FeB | .0015 | 11.1 | 104.0 | 23.8 | 8 | 2.6 | 1.48 |
| 73.. | .64 | .48 | .21 | .0034 | .0035 | .0069 | FeB | .0080 | 13.4 | 77.2 | 49.5 | 8 | 2.6 | 1.71 |
| 74.. | .69 | .51 | .27 | .0001 | .0004 | .0005 | TiB | .0030 | 15.0 | 16.7 | 25.0 | 8 | 2.7 | 1.54 |
| 75.. | .70 | .60 | .28 | .0010 | .0034 | .0044 | FeB | .0030 | 12.0 | 117.5 | 22.7 | 8 | 2.7 | 1.36 |
| 76.. | .57 | .47 | .13 | .0007 | .0002 | .0009 | Bortam | .0030 | 13.0 | 26.0 | 78.0 | 8 | 1.9 | 1.65 |
| 77.. | .56 | .55 | .23 | .0007 | .0008 | .0017 | Carbortam | .0030 | 14.8 | 56.1 | 41.0 | 8 | 2.4 | 1.56 |
| 78.. | .61 | .53 | .22 | .0007 | .0027 | .0034 | FeB | .0040 | 15.4 | 87.3 | 20.6 | 8 | 2.6 | 1.62 |
| 79.. | .61 | .59 | .32 | .0008 | .0042 | .0050 | FeB | .0060 | 15.2 | 84.5 | 16.0 | 8 | 2.7 | 1.43 |
| 80.. | .60 | .53 | .34 | - | - | 9/.0028 | Silvaz | .0030 | 15.3 | 95.2 | - | 8 | 2.7 | 1.13 |
| 81.. | .58 | .52 | .25 | .0009 | .0015 | .0024 | CrB | .0030 | 15.0 | 80.0 | 37.5 | 8 | 2.35 | 1.58 |
| 82.. | .62 | .56 | .28 | .0008 | .0014 | .0022 | MnB | .0030 | 14.75 | 72.3 | 36.3 | 8 | 2.65 | 1.51 |
| 83.. | .62 | .58 | .25 | .0012 | .0014 | .0026 | BC | .0030 | 15.8 | 91.1 | 46.2 | 8 | 2.5 | 1.45 |
| 84.. | .62 | .56 | .23 | .0036 | .0046 | .0082 | FeB | .0100 | 15.2 | 82.8 | 44.0 | 8 | 2.7 | 1.56 |
| 85.. | .61 | .52 | .25 | .0033 | .0052 | .0085 | FeB | .0140 | 15.3 | 61.8 | 39.0 | 8 | 2.7 | 1.65 |
| 86.. | .69 | .60 | .23 | .0023 | .0035 | .0058 | FeB | .0080 | 15.0 | 72.6 | 39.7 | 8 | 2.5 | 1.36 |
| 87.. | .71 | .58 | .24 | .0008 | .0032 | .0040 | FeB | .0050 | 14.5 | 77.5 | 20.0 | 8 | 2.6 | 1.38 |
| 88.. | .65 | .58 | .22 | .0002 | .0003 | .0005 | FeB | .0008 | 15.0 | 62.5 | 40.0 | 8 | 2.6 | 1.47 |
| 89.. | .52 | .53 | .29 | .0015 | .0032 | .0047 | Borosil | .0050 | 15.3 | 96.0 | 31.9 | 8 | 2.5 | 1.65 |
| 90.. | .58 | .52 | .32 | - | - | 9/.0022 | Silcaz | .0020 | 15.0 | 110.0 | - | 8 | 2.65 | 1.47 |
| 91.. | .60 | .55 | .35 | - | - | 9/.0034 | Silcaz | .0030 | 15.25 | 115.0 | - | 8 | 2.75 | 1.28 |
| 92.. | .61 | .49 | .28 | .0010 | .0020 | .0030 | Na ₂ B ₄ O ₇ | 4 gr. | 17.5 | - | 33.3 | 8 | 2.6 | 1.65 |
| 93.. | .61 | .45 | .16 | .0010 | .0020 | .0030 | B ₂ O ₃ | 3 gr. | 17.0 | - | 33.3 | 8 | 1.9 | 1.61 |
| 94.. | .59 | .52 | .25 | .0003 | .0013 | .0016 | Na ₂ B ₄ O ₇ | 3 gr. | 16.5 | - | 18.8 | 8 | 2.2 | 1.50 |
| 95.. | .50 | .48 | .30 | .0017 | .0027 | .0044 | NiB | 0.0050 | 15.5 | 90.6 | 38.6 | 8 | 2.2 | 1.67 |
| 96.. | .61 | .56 | .26 | .0023 | .0033 | .0056 | BC | .0050 | 16.0 | 119 | 41.1 | 8 | 2.9 | 1.60 |
| 97.. | .67 | .54 | .24 | .0019 | .0060 | .0079 | FeB | .0080 | 14.6 | 96.1 | 24.1 | 8 | 2.6 | 1.50 |
| 98.. | .64 | .73 | .29 | .0007 | .0035 | .0042 | MnB | .0050 | 14.4 | 80.7 | 16.7 | 8 | 3.2 | 1.33 |
| 99.. | .26 | .67 | .37 | .0015 | .0015 | .0030 | C | .0050 | 12.5 | 50.0 | 50.0 | 8 | 2.1 | 1.72 |
| 100.. | .59 | .57 | .20 | .0012 | .0017 | .0029 | F | .0050 | 15.0 | 58.1 | 41.4 | 8 | 2.5 | 1.54 |
| 101.. | .63 | .63 | .20 | .0006 | .0010 | .0016 | G | .0050 | 15.0 | 32.0 | 37.5 | 8 | 2.1 | 1.28 |
| 102.. | .64 | .62 | .27 | .0090 | .0150 | .0240 | FeB | .0300 | 13.5 | 72.1 | 37.5 | 8 | 10/ | - |
| 103.. | .61 | .69 | .28 | .0016 | .0042 | .0058 | NiB | .0050 | 12.75 | 98.5 | 27.5 | 8 | 2.75 | 1.33 |
| 104.. | .61 | .60 | .28 | .0003 | .0016 | .0019 | TiB | .0040 | 15.5 | 49.2 | 15.8 | 8 | 2.9 | 1.52 |
| 105.. | .63 | .53 | .24 | .0004 | .0027 | .0031 | CrB | .0050 | 15.5 | 64.0 | 12.9 | 8 | 2.25 | 1.46 |
| 106.. | .60 | .68 | .28 | .0003 | .0034 | .0037 | TiB | .0080 | 15.5 | 44.0 | 8.8 | 8 | 2.85 | 1.38 |
| 107.. | .63 | .67 | .22 | .0005 | .0033 | .0038 | Na ₂ B ₄ O ₇ | 2 gr. | 15.0 | - | 13.2 | 8 | 2.7 | 1.37 |
| 108.. | .52 | .50 | .22 | .0004 | .0003 | .0007 | TiB | 0.0020 | 16.5 | 38.4 | 57.2 | 8 | 2.1 | 1.63 |
| 109.. | .72 | .64 | .20 | .0021 | .0052 | .0073 | B ₂ O ₃ | 4 gr. | 15.0 | - | 29.8 | 8 | 2.4 | 1.25 |
| 110.. | .58 | .60 | .21 | .0008 | .0033 | .0041 | B ₂ O ₃ | 2 gr. | 15.5 | - | 19.5 | 8 | 2.7 | 1.56 |
| 111.. | .61 | .64 | .25 | .0002 | .0015 | .0017 | Bortam | 0.0030 | 14.75 | 55.7 | 11.8 | 8 | 2.6 | 1.39 |
| 112.. | .59 | .52 | .18 | .0002 | .0008 | .0010 | Bortam | .0050 | 16.0 | 21.3 | 20.0 | 8 | 2.3 | 1.59 |
| 113.. | .55 | .72 | .41 | .0003 | .0007 | .0010 | Borosil | .0030 | 13.5 | 39.0 | 33.3 | 8 | 2.9 | 1.30 |
| 114.. | .62 | .57 | .17 | .0006 | .0017 | .0023 | C | .0050 | 16.0 | 49.0 | 26.1 | 8 | 2.6 | 1.57 |
| 115.. | .61 | .62 | .23 | .0006 | .0020 | .0026 | Carbortam | .0030 | 15.25 | 88.5 | 23.1 | 8 | 2.8 | 1.53 |
| 116.. | .51 | .49 | .25 | .0007 | .0034 | .0041 | Borosil | .0050 | 15.5 | 85.0 | 17.1 | 8 | 2.5 | 1.59 |
| 117.. | .65 | .65 | .49 | - | - | 9/.0038 | Silcaz | .0050 | 14.2 | 72.0 | - | 8 | 3.3 | 1.15 |
| 118.. | .74 | .60 | .39 | - | - | 9/.0038 | Silvaz | .0050 | 14.4 | 73.0 | - | 8 | 2.6 | .80 |
| 119.. | .58 | .59 | .41 | - | - | 9/.0035 | Silcaz | .0030 | 15.5 | 120.0 | - | 8 | 3.7 | 1.29 |

1/ Efficiency of boron addition is equal to

$$\frac{\text{Percent total boron as found by chemical analysis}}{\text{Percent added boron} \left(\frac{15}{\text{Actual ingot weight}} \right)} \times 100$$

because the boron addition was based upon an ingot weight of 15 pounds, which was seldom obtained.

2/
$$\frac{\text{Percent soluble boron}}{\text{Percent total boron}} \times 100.$$

3/ J_x is the distance, in sixteenths, along side of Jominy bar from the end-quenched face to the position of 50 percent martensite.

4/ Multiplying factor due to boron as found by calculation.

5/ Heat numbers 6, 7, and 15 were lost.

6/ Envelope containing the boron addition agent was plunged into molten steel bath by means of an iron wire.

7/ The boron addition agent was placed in the end of an iron rod that had been drilled for this purpose. The end of the rod was then closed by an iron plug. When this end was plunged into the steel bath and stirred, it dissolved and thus introduced the boron into the melt.

8/ Carbon too low for standard Jominy hardenability test.

9/ Percentage of boron determined by the distillation method instead of the colorimetric method.

10/ Ingot was hot-short; Jominy bar could not be forged.

TABLE 3. - Supplement to table 2

| Heat No. | Percent total Ti | M. F. due to Ti | Percent total V | M. F. due to V | M. F. due to "residuals" | General M. F. for cal. |
|-----------|------------------|-----------------|-----------------|----------------|--------------------------|------------------------|
| 48 | 0.065 | 1.36 | - | - | 1.07 | 1.46 |
| 54 | .074 | 1.42 | 0.080 | 1.14 | 1.07 | 1.73 |
| 57 | .074 | 1.42 | .092 | 1.16 | 1.07 | 1.76 |
| 58 | .094 | 1.52 | - | - | 1.07 | 1.63 |
| 65 | .035 | 1.19 | - | - | 1.07 | 1.27 |
| 80 | .044 | 1.25 | 0.061 | 1.105 | 1.07 | 1.48 |
| 90 | .016 | 1.09 | - | - | 1.07 | 1.17 |
| 91 | .037 | 1.20 | - | - | 1.07 | 1.28 |
| 117 | .029 | 1.16 | - | - | 1.07 | 1.24 |
| 118 | .058 | 1.32 | 0.087 | 1.15 | 1.07 | 1.62 |
| 119 | .054 | 1.30 | - | - | 1.07 | 1.39 |

Comparison of Boron Addition Agents Based upon Their Chemical Composition

(a) From the standpoint of their effect upon the hardenability of the steel. - It has been observed that elements other than boron present in most of the boron-bearing agents will not increase hardenability measurably. However, silvaz and silcaz are exceptions. For instance, when 0.005 percent boron is added as silvaz, 0.10 percent titanium, 0.10 percent vanadium, 0.06 percent zirconium, 0.06 percent aluminum, and 0.37 percent silicon are added coincidentally. This silicon supplies part of total silicon required, and its effect on the hardenability, therefore, is taken into account. Most of the aluminum and zirconium is lost by oxidation, but some of the titanium and vanadium will alloy with the steel and exert an influence on the hardenability. Although the effects of titanium and vanadium on hardenability have not been definitely established, it is believed that the vanadium thus introduced will increase the hardenability, whereas the titanium may decrease it. The same reasoning may be applied to the silcaz addition, except that vanadium is not present.

(b) From the standpoint of their effect on melting practice. - Because silcaz, silvaz, and borosil contain approximately 40 percent silicon, whereas bortam contains 21 percent, the final silicon analysis of the melt is likely to be higher than desired, unless this fact is taken into account by the melter.

Other Observations Regarding the Use of Boron Addition Agents

1. Ferro-boron was an excellent source of boron, giving the best over-all results.

2. A suggestion that chromium boride might not dissolve in steel but, instead, might become hard inclusion material is found in the work of

Cole and Edmonds.^{47/} However, neither it nor boron-carbide, supposedly one of the hardest constituents known, caused any machining difficulties in the steels investigated in this work.

3. Boron-carbide tended to produce an explosive reaction when it was added to the molten steel. Furthermore, it also tended to give poor ingot surface.

4. Titanium boron had a greater tendency to cause the retention of austenite than the other sources of boron. It also caused excessive pipe in the ingot.

5. Manganese-boron and nickel-boron alloys, commonly used to deoxidize nonferrous alloys and improve their physical properties, were found to be satisfactory sources of boron for steel.

6. Additions of silvaz and silcaz, as well as titanium-boride to a lesser extent, appeared to dissolve with difficulty in the molten steel.

7. In spite of information to the contrary, both pyrobor (dehydrated borax with formula $\text{Na}_2\text{B}_4\text{O}_7$) and fused boron trioxide glass (B_2O_3) proved to be good sources of boron for steel. It was found that 5 grams of pyrobor or 4 grams of the trioxide glass would add 0.005 percent (total) boron to the steel (15 pound ingot), whereas 69 grams of silcaz, 77 grams of silvaz, 11 grams of borosil, or 4.15 grams of ferro-boron were otherwise necessary to obtain the equivalent boron content. In addition, the quantity of boron obtainable from these two agents did not seem to be limited. For example, in heat No. 23, 10.9 grams of the boron trioxide glass added 0.0123 percent total boron to the steel. These facts are contradictory to Gurry's statement^{48/} that borax could be reduced only to a slight extent on a well-deoxidized bath, and that only about 0.001 percent boron could thus be introduced into the steel. Therefore, as pyrobor and boron trioxide glass could be cheap, easily obtainable sources of boron for steel, their method of use in connection with commercial-size open-hearth heats of steel deserves further study.

Observations on the Chemical Determination of Boron in Steel

Chemical Method Used

To determine the percentage of boron present in the steels, the colorimetric method using quinalizarin was employed. This method was developed by the Youngstown Sheet & Tube Co., and has been reported recently by Rudolph and Flickinger.^{49/}

^{47/} Cole, N. W., and Edmonds, W. H., Hardening Material Resistant to Heat, Acid, Corrosion, and Abrasion, and Method of Producing the Same: U. S. Patent 2,088,838, August 3, 1937.

^{48/} Gurry, R. W., The Relative Deoxidizing Power of Boron in the Open-Hearth Process: Metals Technol., Tech. Paper 1641, December 1943, 5 pp.

^{49/} Work cited in footnote 28.

The method is simple. Ordinary glassware is used; moreover, by this method an experienced chemist can determine the percentage of boron in 15 to 20 samples of steel in eight hours.

(a) Accuracy of the method. - An experienced analyst can detect 0.0002 percent boron in either the soluble or insoluble portion of the steel, giving a precision of 0.0004 percent for the total boron of the sample.

As a further illustration of the accuracy of the method, a group of samples that had been analyzed by the distillation-titration method^{50/} by another laboratory was run. That the results compared very favorably, may be seen from table 4.

TABLE 4. - Comparison of methods for the determination of boron

| Sample | Total boron, percent | |
|---------|----------------------|------------------------|
| | Colorimetric | Distillation-titration |
| 1 | 0.0024 | 0.0021 |
| 2 | .0031 | .0030 |
| 3 | .0031 | .0029 |
| 4 | .0051 | .0047 |
| 5 | .0044 | .0041 |
| 6 | .0041 | .0045 |
| 7 | .0008 | .0010 |

(b) Precision of the method. - Table 5 indicates the precision obtainable with the colorimetric method. A different set of color standards and stock solutions was used for each value shown. Also included are the results obtained by another laboratory using the same procedure.

TABLE 5. - Precision of colorimetric method

| | Total boron, percent | |
|-----------------------------|----------------------|-----------|
| | Sample 38 | Sample 46 |
| May 20 | 0.0054 | 0.0031 |
| July 19 | .0052 | .0033 |
| September 3 | .0055 | .0033 |
| October 20 | .0052 | .0034 |
| December 10 | .0055 | .0032 |
| By another laboratory | .0050 | .0034 |

(c) Difficulties encountered while using the colorimetric method. - The only trouble encountered in the use of the colorimetric method was in the analysis of steels to which boron had been added by means of silvaz and silcaz. It was found that the color developed in the acid-soluble portions of

^{50/} The distillation-titration method for the determination of boron in steel is a long procedure requiring the use of boron-free Corning No. 728 glassware.

these steels was not stable but continued to change toward a bluer color even after 24 hours. The cause of this interference has not been determined, but it is believed that an accurate boron value is obtained if the comparison with the standards is made as soon as possible after the addition of quinalizarin. To check this point, these steels were analyzed for boron by the distillation-titration method. Most of the results by the two methods compare satisfactorily, as shown in table 6.

TABLE 6. - Determination of boron in steels to which silvaz and silcaz had been added.

| Sample | Total boron determined, percent | |
|--|---------------------------------|------------------------|
| | Colorimetric | Distillation-titration |
| 48 | 0.0054 | 0.0051 |
| 54 | .0037 | .0040 |
| 57 | .0045 | .0053 |
| 58 | .0044 | .0052 |
| 65 | .0038 | .0022 |
| 80 | .0022 | .0028 |
| 86 | .0059 | .0059 |
| 90 | .0019 | .0022 |
| 91 | .0032 | .0034 |
| 117 | .0042 | .0038 |
| 118 | .0042 | .0038 |
| 119 | .0041 | .0035 |
| Bureau of Standard's sample 151 containing 0.0027 percent total boron | .0027 | .0027 |

Relationships Concerning the Percentage of Soluble and Insoluble Boron in Steel

The determination of boron in steel involves finding the percentage of boron present in an insoluble and a soluble portion of the sample, the total boron in the steel being the sum of the boron found in both portions.

(a) Variation in soluble and insoluble boron with change in total boron for boron steels of similar analyses. - If the percentage of soluble and insoluble boron is plotted against the percentage of total boron for the 12 boron steels^{51/} that fall within the analysis range:

| | | |
|-------------------|--------------------|--------------------|
| <u>C, percent</u> | <u>Mn, percent</u> | <u>Si, percent</u> |
| 0.47/0.57 | 0.58/0.67 | 0.19/0.31 |

^{51/} These 12 steels are Nos. 39, 41, 42, 44, 47, 49, 53, 61, 66, 67, 70, and 72.

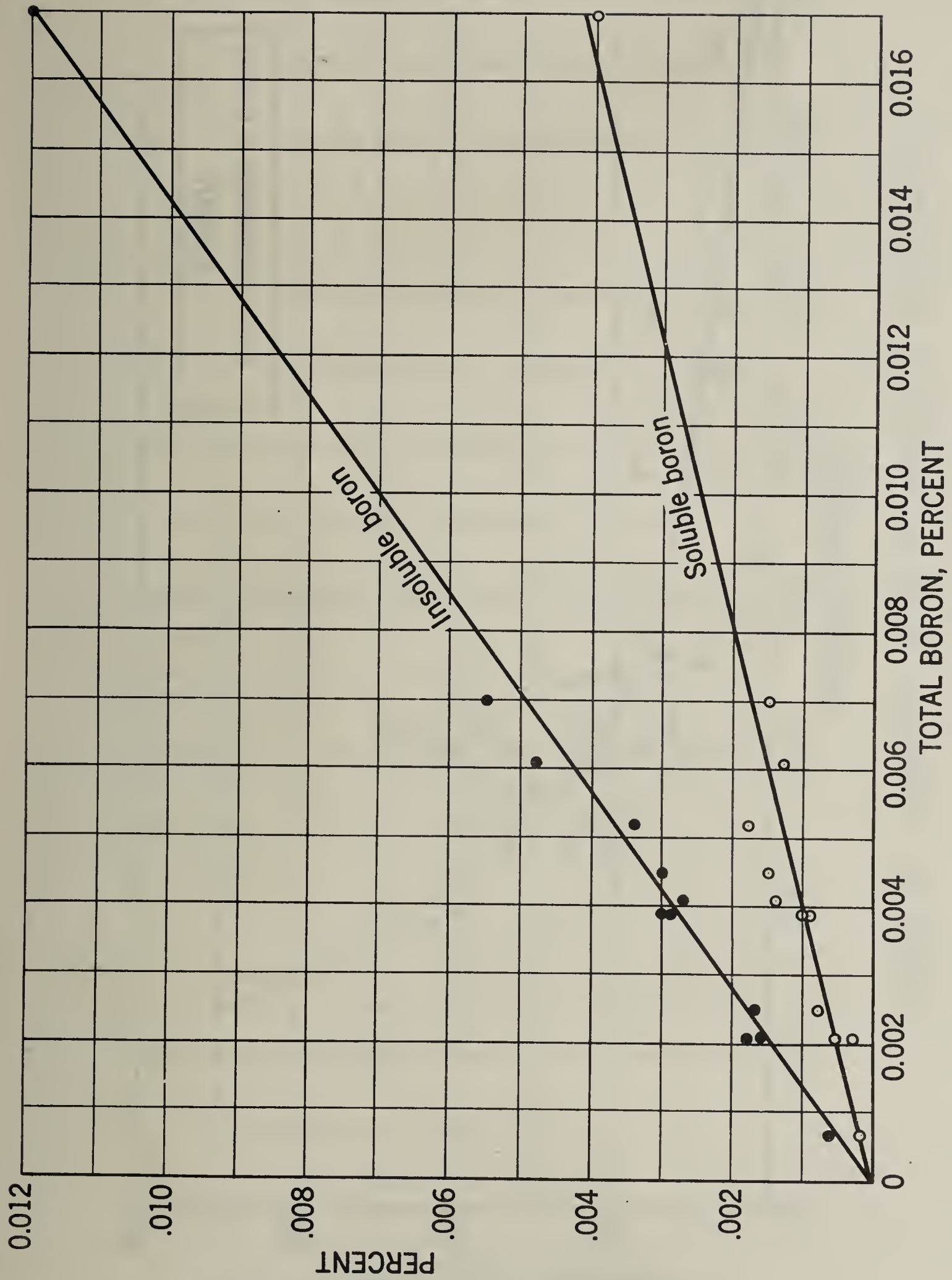


Figure 5 .—Change in soluble and insoluble boron with change in total boron for boron steels of similar analyses.



Graph of $y = x$ and $y = x^2$

Figure 1. Graph of $y = x$ and $y = x^2$

The graph shows the relationship between x and y for the functions $y = x$ and $y = x^2$. The horizontal axis represents x and the vertical axis represents y . The curve $y = x$ is a straight line, while the curve $y = x^2$ is a parabola opening upwards.

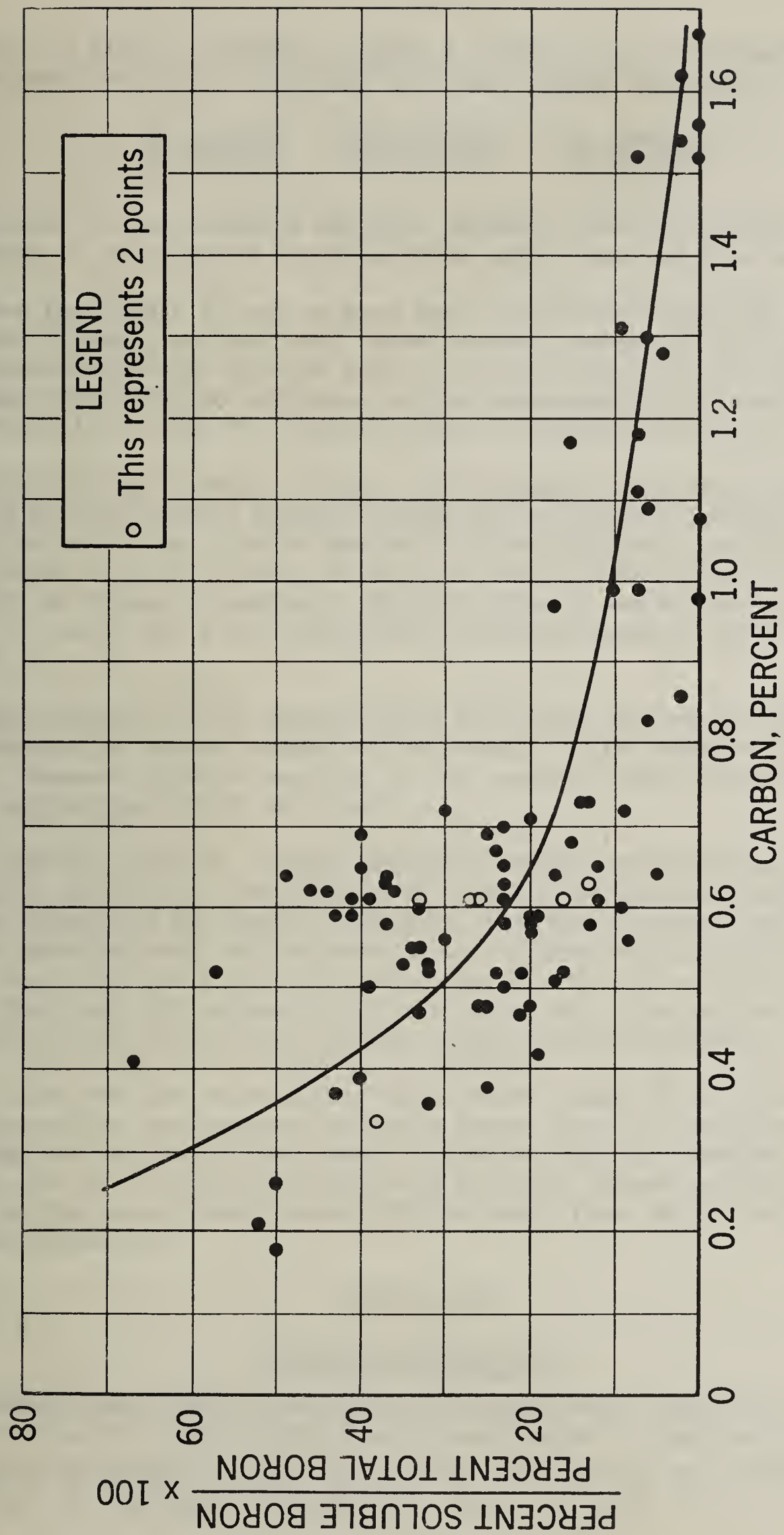


Figure. 6 .—Effect of carbon on percent of soluble boron.

the graph of figure 5 results. Also, a similar graph is obtained when a plot is made for the 21 steels^{52/} that fall within the range:

| <u>C, percent</u> | <u>Mn, percent</u> | <u>Si, percent</u> |
|-------------------|--------------------|--------------------|
| 0.58/0.65 | 0.52/0.63 | 0/20/0.35 |

In addition, it was observed that the tendency shown by figure 5 occurred regardless of the type of boron addition agent that had been used.

From the figure it may be seen that both the soluble and insoluble boron increased linearly as the total boron content increased, the insoluble portion increasing at the greater rate. It would appear that both soluble and insoluble boron have an influence on the hardenability of steel, and that the distinction in the two kinds is due to chemical procedure.

(b) Effect of carbon, silicon, and manganese upon the soluble boron. - When the percent soluble boron, divided by the percent insoluble boron, multiplied by 100 was plotted against the percentage of carbon for all heats except those to which silvaz, silcaz, bortam, and carbortam had been added, the graph of figure 6 resulted. In this figure, the spread of the plotted points is due to the wide variation in chemical composition of the heats plotted.

From figure 6, it is evident that the amount of soluble boron decreases with increase in carbon content of the steel. This behavior indicates a gradual increase in boron carbide in the insoluble portion with increase in the carbon content of the steel.

A similar curve is obtained likewise if the percent soluble boron divided by the percent insoluble boron times 100 is plotted against the silicon content of the steel, indicating thereby that the insoluble boron portion increased with an increase in the silicon content of the steel. That a chemical tie-up existed between boron and silicon also was indicated by the fact that the percentage of silica in the extracted inclusion material increased as the total boron content of the steels increased.

A third similar relationship also existed when the percent soluble boron divided by the percent insoluble boron times 100 was plotted against the manganese content of the steel. In this instance, however, the MnO and MnS content of the extracted inclusion material seemed unaffected by any change in the total boron content of the steel from which the inclusions had been extracted.

CONCLUSIONS

Specific Conclusions

Although the results previously discussed were obtained by experimental laboratory work on small induction-furnace heats of steel and have not yet

^{52/} These 21 steels are Nos. 40, 56, 71, 78, 79, 80, 81, 82, 84, 85, 90, 91, 94, 96, 100, 101, 104, 105, 110, and 115.

been applied to commercial practice, it is believed that they are applicable to commercial-size heats, this contention having been verified by a number of other investigators. For instance, Crafts,⁵³ who also used the induction furnace while investigating the effects of boron in steel, observed that both the hardenability and ductility of laboratory prepared steels were surpassed when the same compositions were made in the open hearth.

With the above in mind, the following specific conclusions are advanced as a summary of this investigation:

1. Boron should be regarded as any other element added to steel to increase the hardenability, and its use should not be expected to be a "cure-all" for improper steel-making practice.

2. The colorimetric method developed by the Youngstown Sheet & Tube Co. for the determination of the percentage of boron in steel was examined and found to be simple, accurate, precise, and rapid. In addition, interesting relationships were found to exist between the percentages of soluble, insoluble, and total boron in a steel, and the effects of carbon, silicon, and manganese on these portions were determined.

3. Contrary to the general belief, boron may be used to produce fine-grained steels of good forging characteristics. The boron steels examined had good hardenability at low alloy content and were uniform in structure and consistent in behavior.

4. Boron may be added to steel by means of a number of boron addition agents. These agents were compared upon the basis of their effect upon melting practice as well as upon the hardenability of the steel. In spite of information to the contrary, both pyrobor (dehydrated borax) and fused boron trioxide glass, which are inexpensive, appear to be suitable sources of boron for steel.

5. Boron, regardless of the method of addition to steel, has a specific effect on hardenability; in other words, a certain percentage of boron in steel increases the hardenability by a fixed amount.

6. The multiplying factor for the hardenability conferred by boron to steel was determined and found to increase in proportion to the boron content up to a maximum value of 1.58 at 0.003 percent total boron. With further increase in boron content above 0.003 percent, the multiplying factor decreased.

7. Minute amounts of boron will increase the hardenability of steel comparable to that produced by much larger additions of other more common alloying elements. For instance, it was shown that 0.003 percent total boron in steel has an effect on the hardenability equal to a silicon content of 0.87 percent, a nickel content of 0.79 percent, a chromium content of 0.27 percent, a manganese content of 0.12 percent, or a molybdenum content of 0.23 percent.

8. It should not be construed from this paper that the use of boron will eliminate the usefulness of the more common alloying elements, as the increase in hardenability due to the addition of boron is limited; furthermore, properties other than hardenability must of necessity be supplied as formerly by elements other than boron.

General Conclusions

As an alloying element, boron is chiefly added to steel either to increase its hardenability or to replace, partly or entirely, a more strategic or valuable alloying element. In the latter case, the hardenability imparted to the steel by the boron must be equivalent to that formerly given the steel by the alloying element that has been replaced.

Generally, boron is most valuable in medium-carbon steels, because high-carbon steels have sufficient innate hardenability, whereas low-carbon steels are not intended to be hardened by quenching.

Boron may be added to steels conforming to S. A. E. specifications, keeping the alloys on the low side; or entirely new steels may be made by adding 0.003 percent total boron to a carbon steel along with the other alloys necessary to obtain the desired physical properties.

As steel-making practice varies considerably from shop to shop, only general recommendations can be made for using the boron addition agents. First, in order to obtain a good recovery, the boron should be added to thoroughly killed steel. Second, for good dissemination of the boron throughout the steel, the boron should be added in several portions to the ladle as it fills and before the slag starts to flow into it.

Processing the boron steel from the ingot to the desired rolled section may be accomplished without experiencing any particular difficulty, for the boron steel can be worked as readily as steels free of boron.

Once machined or otherwise shaped to size, the boron steel should receive a heat treatment consisting of a liquid quench followed by a low-temperature draw in order to obtain the maximum effects of the boron addition.

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

EFFECT OF VARIABLES IN CHEMICAL BENEFICIATION
OF CHROMITE ORES

APR 15 '49



NAT. HIST.

BY

F. S. BOERICKE AND W. M. BANGERT

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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INTRODUCTION

Previous investigations of the Boulder City station of the Bureau of Mines have demonstrated that low-grade domestic chromite concentrates can be roasted with carbon to obtain selective reduction of the contained iron, and that the reduced iron can be removed by acid leaching of the roasted products to produce residues with higher chromium:iron ratios. Thus, some chromite ores or concentrates that originally contain too much iron to be acceptable for the production of ferrochrome can, by this treatment, be rendered marketable as "high-grade" chromite.^{3/}

The present report supplements the earlier work of the Bureau and records the results of small-scale laboratory tests investigating the effects of:

1. Temperature and time of the reducing roast.
2. Chromite and carbon particle size.
3. Ratio of carbon to chromite in the initial roast mixture.
4. Variations in the alumina and silica content of the ore.
5. Back-oxidation of the roast product.
6. Temperature and time of leaching of roast product.

This work differs from that done previously in that particular emphasis was placed on roast mixtures containing just enough carbon for the reduction of the iron in the chromite, whereas some two and one-half times this amount of carbon was used in the earlier work.

In addition to these tests, the mechanism of the reduction reactions was examined for the purpose of explaining the presence of acid-soluble chromium, which occurs under certain conditions of chromite reduction.

MATERIALS AND METHOD

The chromite investigated in the major part of this work was a concentrate of a typical Montana chrome deposit, the Benbow. Its analysis is:

| | Percent | | Percent |
|--------------------------------|---------|--------------------------------|---------|
| Cr ₂ O ₃ | = 41.3 | Al ₂ O ₃ | = 18.2 |
| FeO | = 24.0 | SiO ₂ | = 1.6 |
| MgO | = 12.9 | Cr/Fe | = 1.51 |

^{3/} As specified Dec. 19, 1941, by the Metals Reserve Co. of Washington, D. C., "high-grade" chromite must have a minimum Cr:Fe ratio of 2.5 and a Cr₂O₃ content of not less than 45 percent.

In a later part of the report, results for the Benbow concentrate are compared with those of three other typical chromites, from the Davis, Antelope, and Seiad properties. The analyses of these chromites are as follows:

Davis property, Silver Star, Montana
(picked high-grade)

| | <u>Percent</u> | | <u>Percent</u> |
|--------------------------------|----------------|--------------------------------|----------------|
| Cr ₂ O ₃ | = 37.9 | Al ₂ O ₃ | = 18.0 |
| FeO | = 27.4 | SiO ₂ | = 1.9 |
| MgO | = 9.4 | Cr/Fe | = 1.22 |

Antelope (composite, table concentrate), Madison County,
Montana, approximate assay

| | | | |
|--------------------------------|--------|--------------------------------|-------|
| Cr ₂ O ₃ | = 36 | Al ₂ O ₃ | = 26 |
| FeO | = 24.4 | SiO ₂ | = 6 |
| MgO | = 13 | Cr/Fe | = 1.3 |

Seiad (table concentrate), California,
approximate assay

| | | | |
|--------------------------------|--------|--------------------------------|--------|
| Cr ₂ O ₃ | = 52.8 | Al ₂ O ₃ | = 4.8 |
| FeO | = 23.6 | SiO ₂ | = 1.4 |
| MgO | = 10.3 | Cr/Fe | = 1.97 |

Although the Cr₂O₃ content of these four ores varies between 36 and 52.8 percent, the FeO content is fairly constant. It is calculated that the carbon:chromite ratio required for the reduction of the iron alone is approximately 0.04 for the Benbow, Antelope, and Seiad samples and 0.045 for the Davis sample, assuming that all the iron in the ores is in the ferrous condition.

All runs except two were made with "Norblack," a fine-size variety of commercial carbon analyzing 99.7 percent carbon and 0.17 percent ash. The remaining impurity is largely bound hydrogen removable only by chemical means. Two runs, for comparison, were made with graphite analyzing 99.98 percent carbon and 0.03 percent ash.

The method consisted of roasting an intimate mixture of chromite and carbon at a specified temperature for a specified time, then leaching out the acid-soluble iron and chromium and analyzing the leach solution and the ignited residue.

The roast charge, containing 10 or 15 grams of chromite and a specified amount of carbon, was placed in a covered alundum thimble inside a gas-tight porcelain tube and heated in either a tube furnace or a large muffle furnace. In most instances the porcelain tube was evacuated to 0.01 mm. before heating, but in a few runs the air was removed from the tube by flushing with pure, dry helium. In the earlier experiments, the porcelain tube was

connected to a gas receiver for measuring the volume of carbon monoxide evolved during the reduction. A time-volume record of gas evolution was obtained, which indicated the approximate speed of the reduction and furnished some comparison data that otherwise would not have been apparent, especially when the roasting period was of several hours' duration. The total time of roasting will be recorded for each of the earlier roasts, accompanied by a record of the time necessary to evolve 90 percent of the carbon monoxide actually produced in the entire roasting period. It is assumed that the time of evolution of 90 percent of the total carbon monoxide corresponds approximately to the time that would be required to reduce and render acid-soluble 90 percent of the metal which is recorded as acid-soluble for the run. However, the measurement of the carbon monoxide evolved is somewhat uncertain because of the hydrogen content of the "Nor-black." Approximate allowance has been made for the hydrogen, but even so, the carbon monoxide figures are subject to a few percent error.

Most of the leaching was done with 10 percent sulfuric acid, 100 cc. per gram of roast product being used. The acid was added warm, brought rapidly to boiling, and finally allowed to digest the roast product for one hour at 80° C. This method was found to remove virtually all the soluble iron and chromium, as shown by repeating the leaching in a few instances and varying the acid-strength and time of leaching in others. A few leaching experiments were carried out with cold 10 percent sulfuric acid and with stronger cold sulfuric acid to determine the effect of leaching temperature upon extraction.

In all, data are complete for some 100 tests, of which approximately 70 concern the Benbow sample, the remainder being divided among the Seiad, Antelope, and Davis samples.

EXPERIMENTAL RESULTS

Effects of Temperature and Time

Preliminary orienting experiments showed that the present procedures gave results similar to those obtained in earlier work of the Bureau. A temperature of at least 1,200° is necessary for removal of 60 percent of the iron in any reasonable time, as may be seen from table 1, in which three of the preliminary and one of the later tests are recorded. In this table and in those that follow the theoretical amount of carbon monoxide is based upon the total carbon in the charge.

It is seen in table 1 that at 1,075° only 21 percent of the total iron is reduced in a 7-hour treatment, 48 percent in 7 hours at 1,150°, and 60 percent in 5.5 hours at 1,200°. It is significant that, according to the carbon monoxide evolution, 90 percent of the reduction occurring at both 1,075° and 1,150° required 5 hours, whereas only 2 hours were needed at 1,200°. In the 1,300°-run, 71 percent of the iron was reduced in 6 hours, but only 0.67 hour was necessary for producing 90 percent of this result.

TABLE 1. - Results of roasting-temperature tests

| Run | Temp., °C. | Ratio C:chromite | Mesh size of chromite | Time, hr. | CO, percent of theoretical | |
|----------|---------------|---------------------|--------------------------|--------------|----------------------------------|--|
| 1 | 1,075 | 0.040 | -65 | 7 | 29 | |
| 2 | 1,150 | .040 | -65 | 7 | 62 | |
| 3 | 1,200 | .040 | -65 | 5.5 | 76 | |
| 19 | 1,300 | .040 | -65 | 6 | 86 | |

| Run | Time of evolution of 90 percent of CO, hr. | Fe removed, percent | Cr lost, percent | Ignited residue | | |
|----------|---|---------------------------|---------------------|-----------------|---|----------------|
| | | | | FeO, percent | Cr ₂ O ₃ percent | Cr:Fe ratio |
| 1 | 5 | 21.4 | 0.0 | 20.3 | 45.1 | 1.9 |
| 2 | 5 | 48.5 | .25 | 13.7 | 49.0 | 3.1 |
| 3 | 2 | 60 | 2.3 | 11.5 | 49.5 | 3.7 |
| 19 | 0.67 | 71 | 1.5 | 8.7 | 50.0 | 5.1 |

Further tests at 1,200°, 1,300°, and 1,400° are recorded in table 2.

With just enough carbon present to reduce the iron at 1,200°, 57 per cent of the iron was removed after a 5.5-hour treatment, of which 90 percent could have been removed after 2 hours. At 1,300°, the corresponding figures are 73 percent iron removal after a 6-hour treatment, of which 90 percent would have been possible after 0.5 hour. The shorter runs, 25, 26, and 27, at 1,300° show comparable total iron reduction for roasting periods of 0.5, 1, and 2.25 hours. Thus, in the small-scale tests, with fine chromite ore and fine carbon, roasting time in excess of 0.5 hour is unnecessary at 1,300°.

The last three runs in table 2 were made with an excess of carbon, as indicated. It is seen that a 0.5-hour treatment at 1,400° reduces more iron than a 1-hour treatment at 1,300° or a 6-hour treatment at 1,200°.

It appears, therefore, that treatment times in the ratios of about 1 to 2 to 10, at 1,400°, 1,300°, and 1,200°, respectively, produce about the same amount of extractable iron.

Also, table 2 shows that the chromium:iron ratios of the residues have been raised to from 3.4 to 6.7, as compared with 1.51 for the original concentrate. Chromium losses are small in the runs with just enough carbon to reduce the iron and quite large in the runs with excess carbon. This will be discussed in a later section.

TABLE 2. - Results of roasting temperature-time tests

| Run | Temp., °C. | Ratio C:chromite | Mesh size, chromite | Time, hr. | CO, percent of theoretical |
|----------|---------------|---------------------|------------------------|--------------|----------------------------------|
| 5 | 1,200 | 0.040 | -200 | 5.5 | 68 |
| 25 | 1,300 | .040 | -200 | 0.5 | a/ |
| 26 | 1,300 | .040 | -200 | 1 | a/ |
| 27 | 1,300 | .040 | -200 | 2.25 | a/ |
| 18 | 1,300 | .040 | -200 | 6 | 87 |
| 30 | 1,400 | .040 | -200 | 0.5 | 96 |
| 10 | 1,200 | .067 | -200 | 6 | 71 |
| 31 | 1,300 | .067 | -200 | 1 | a/ |
| 52 | 1,400 | .067 | -200 | 0.5 | a/ |

| Run | Time of evolution of 90 percent of CO, hr. | Fe removed, percent | Cr lost, percent | Ignited residue | | |
|----------|---|---------------------------|---------------------|-----------------|---|----------------|
| | | | | FeO, percent | Cr ₂ O ₃ , percent | Cr:Fe ratio |
| 5 | 2 | 57 | 0.2 | 12.5 | 48.3 | 3.4 |
| 25 | 0.33 | 76 | 1.4 | 7.3 | 50.0 | 6.0 |
| 26 | 0.5 | 69 | 1.0 | 9.2 | 49.4 | 4.7 |
| 27 | 0.33 | 74 | 1.3 | 7.8 | 50.0 | 5.6 |
| 18 | 0.5 | 73 | 1.2 | 8.4 | 51.0 | 5.3 |
| 30 | 0.25 | 69 | 1.7 | 10.4 | 51.4 | 4.4 |
| 10 | 2 | 75 | 12 | 8.4 | 47.8 | 5.0 |
| 31 | 0.33 | 78 | 15 | 8.8 | 50.1 | 5.0 |
| 52 | 0.25 | 84 | 16 | 6.5 | 49.8 | 6.7 |

a/ Only relative volume of carbon monoxide was measured.

Figure 1 shows the carbon monoxide evolution plotted against time for the various temperatures studied and demonstrates, more clearly than tables 1 and 2, the effect of temperature upon rate of reduction. In this figure, the amounts of carbon monoxide evolved during each time interval are calculated from the measured total volume of gas, with due correction for the hydrogen content, and are expressed as percent of the theoretical amount of carbon monoxide that would be produced if all the carbon of the charge reacted to form this gas. In practice, this figure approaches but never quite reaches 100 percent, because some of the carbon reacts with the reduced metal to form carbides, as is shown by combustion analysis of the roast products and by the distinct smell of hydrocarbon gases evolved during acid leaching. Because of the indeterminate amount of carbide formation and of the uncertainty in the magnitude of the hydrogen correction, these carbon monoxide volumes cannot be used as an exact measure of the amount of reduction. However, regardless of the formation of carbides, the evolution of carbon monoxide must be caused by the reduction of some metal oxide, and therefore a comparison of the carbon monoxide evolution rates furnishes a rough comparison of reduction rates.

For example, if reductions are assumed equivalent when 60 percent of the carbon monoxide is evolved, the following relative times, read from this graph, give an inverse measure of the over-all speed of reduction up to this point:

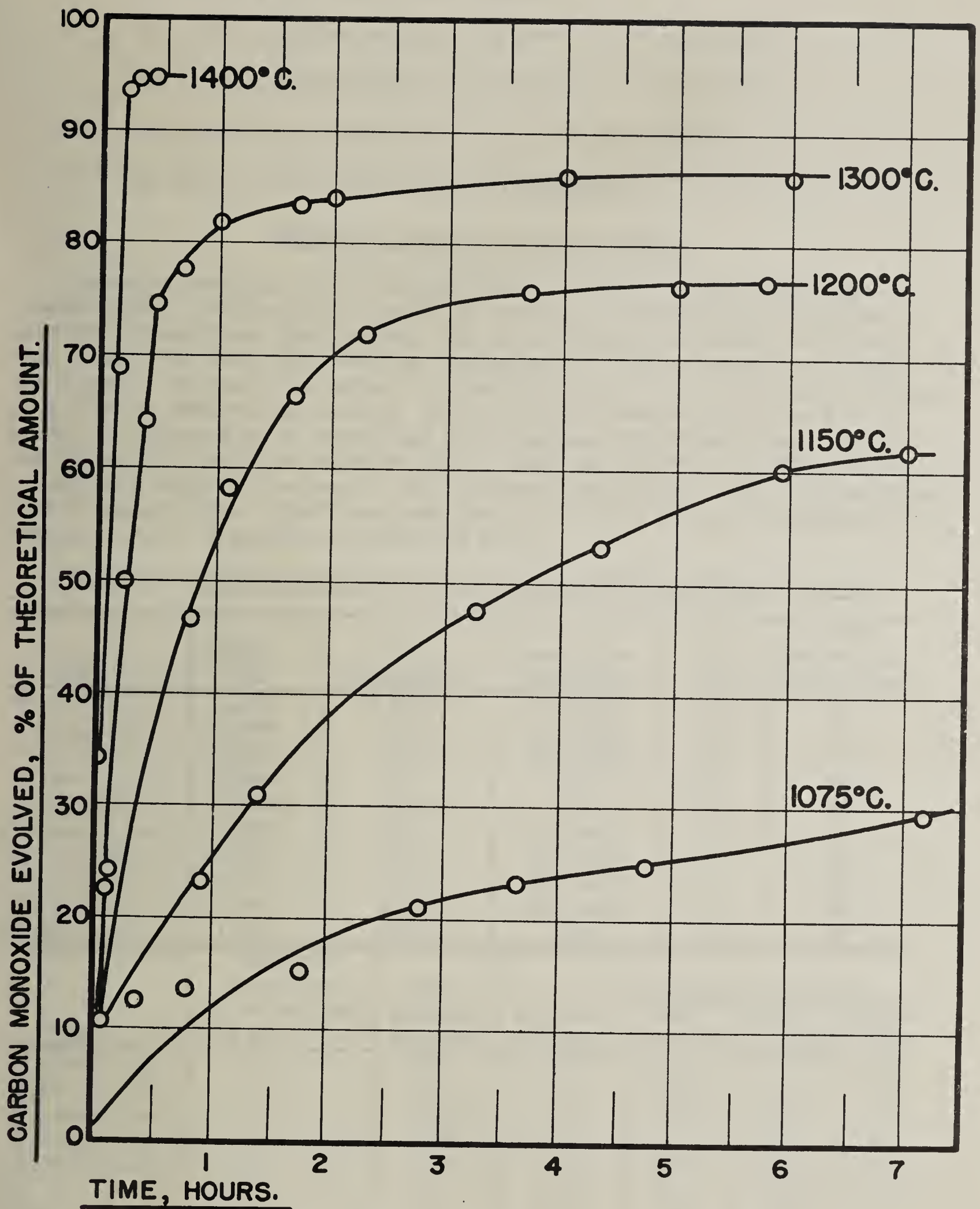


FIGURE 1.- Cumulative rate of reduction of Benbow chromite concentrates by carbon at various temperatures.

At 1,400°, approximately 8 minutes.

At 1,300°, approximately 0.33 hour, or 20 minutes.

At 1,200°, approximately 1.33 hours, or 80 minutes.

At 1,150°, approximately 6 hours, or 360 minutes.

At 1,075°, 12 to 18 hours (extrapolated),

Effect of Chromite Particle Size

Chromite particle sizes ranging from (-14 +28) to -200 mesh were investigated. The results, listed in table 3, show that for chromite particle sizes finer than 28-mesh little difference in amount of reduced iron occurs for over-all roasting treatments of 5.5 to 7 hours at 1,200° and 1,300°. However, the effect of particle size of (-14 +28) mesh material at 1,300° is noticeable, only 57 percent of the iron being reduced in 6 hours, as compared with an average of 70 percent for finer sizes. Also, the effect of size is evident at both 1,200° and 1,300° upon the time required to produce 90 percent of the recorded reductions. This varies from 2 to 4 hours in the 1,200° runs and from 0.5 to 1.5 hours in comparable runs at 1,300°, depending on particle size.

TABLE 3. - Results of tests with varying chromite particle sizes

| Run | Temp., °C. | Ratio C:chromite | Mesh size, chromite | Time, hr. | CO, percent of theoretical | |
|----------|---------------|---------------------|------------------------|--------------|----------------------------------|--|
| 8 | 1,200 | 0.040 | -28 +65 | 6.5 | 69 | |
| 7 | 1,200 | .040 | -65 +100 | 7 | 75 | |
| 6 | 1,200 | .040 | -100 +200 | 6 | 75 | |
| 9 | 1,200 | .040 | -200 | 6 | 68 | |
| 5 | 1,200 | .040 | -200 | 5.5 | 68 | |
| 24 | 1,300 | .040 | -14 +28 | 6 | a/ | |
| 23 | 1,300 | .040 | -28 +65 | 6 | a/ | |
| 22 | 1,300 | .040 | -65 +100 | 6 | a/ | |
| 21 | 1,300 | .040 | -100 +200 | 6 | 84 | |
| 18 | 1,300 | .040 | -200 | 6 | 87 | |

| Run | Time of evolution of 90 percent of CO, hr. | Fe removed, percent | Cr lost, percent | Ignited residue | | |
|----------|---|---------------------------|---------------------|-----------------|---|----------------|
| | | | | FeO, percent | Cr ₂ O ₃ , percent | Cr:Fe ratio |
| 8 | 4 | 59 | 1.7 | 11.9 | 47.2 | 3.5 |
| 7 | 4.5 | 59 | 1.7 | 11.9 | 47.7 | 3.5 |
| 6 | 3 | 56.5 | 1.4 | 12.6 | 48.0 | 3.4 |
| 9 | 2 | 58 | .2 | 13.1 | 49.4 | 3.3 |
| 5 | 2 | 57 | .2 | 12.5 | 48.3 | 3.4 |
| 24 | 4 | 57 | 5.6 | 12.3 | 45.9 | 3.3 |
| 23 | 1.5 | 66 | 1.4 | 9.9 | 48.5 | 4.3 |
| 22 | .5 | 75 | 4.9 | 8.0 | 49.5 | 5.5 |
| 21 | .67 | 68 | 1.3 | 9.5 | 48.6 | 4.5 |
| 18 | .5 | 73 | 1.2 | 8.4 | 51.0 | 5.3 |

a/ Only relative volumes of carbon monoxide were measured.

The tendency is for the chromium losses (i.e., acid-extractable chromium) to be higher for the coarser particles. This appears reasonable in the light of other data to be recorded below and will be discussed later. Thus, it appears that while the over-all iron reduction of particles finer than 28-mesh, during a prolonged treatment, is not greatly affected by particle size, shorter roasting times may be used for finer particles, and chromium losses are less for finer particles.

Effect of Carbon Particle Size

The study of carbon particle size was not stressed, and only two runs were made with sized carbon. These are the runs, previously mentioned, in which graphite was used. The results are listed in table 4.

These meager data indicate that the effect of carbon particle size upon the iron reduction rate is similar to the effect of chromite particle size. A 0.5-hour treatment at 1,300° with -200 mesh graphite reduces about the same amount of iron as a 5-hour treatment with (-14 +28) mesh graphite. A comparison of run 29 with runs 25, 26, and 27 of table 2 shows no marked difference in reactivity of "Norblack" and graphite.

TABLE 4. - Results of tests with varying carbon particle sizes

| Run | Temp., °C. | Ratio C:chromite | Mesh size, carbon | Time, hr. | CO, percent of theoretical |
|------------|---------------|---------------------|----------------------|--------------|----------------------------------|
| 28a/ | 1,300 | 0.040 | -14 +28 | 5 | b/ |
| 29a/ | 1,300 | .040 | -200 | 1.5 | b/ |

| Run | Time of evolution of 90 percent of CO, hr. | Fe removed, percent | Cr lost, percent | Ignited residue | | |
|------------|---|---------------------------|---------------------|-----------------|---|----------------|
| | | | | FeO, percent | Cr ₂ O ₃ , percent | Cr:Fe ratio |
| 28a/ | 3.5 | 65 | 0.6 | 10.5 | 49.1 | 4.1 |
| 29a/ | 0.5 | 72 | 1.1 | 8.4 | 49.5 | 5.2 |

a/ -200 mesh chromite.

b/ Only relative volumes of carbon monoxide were measured.

Effect of Carbon : Chromite Ratio

The effect of the initial carbon:chromite ratio of the roast-mixture was stressed in the present work. In the 20 runs recorded in tables 1 to 4, in which carbon in the amount necessary just for iron reduction was used, the amount of acid-soluble chromium produced was less than 2.5 percent of the chromium in the original concentrate, except in two instances. Table 5 shows the effect of using carbon in amounts exceeding the requirement for iron reduction.

TABLE 5. - Results of tests with varying carbon:chromite ratios
(using -200 mesh Benbow concentrates)

| Run | Temp., °C. | Ratio C:chromite | Fe removed, percent | Cr lost, percent | Ignited residue | | |
|----------|---------------|---------------------|---------------------------|---------------------|-----------------|---|----------------|
| | | | | | FeO, percent | Cr ₂ O ₃ percent | Cr:Fe ratio |
| 5 | 1,200 | 0.040 | 57 | 0.2 | 12.5 | 48.3 | 3.3 |
| 9 | 1,200 | .040 | 58 | .2 | 13.1 | 49.4 | 3.3 |
| 13 | 1,200 | .047 | 60 | 4.1 | 12.7 | 49.6 | 3.4 |
| 12 | 1,200 | .053 | 70 | 5.7 | 9.6 | 48.6 | 4.5 |
| 14 | 1,200 | .060 | 69 | 7.9 | 10.6 | 49.0 | 4.1 |
| 10 | 1,200 | .067 | 75 | 12 | 8.4 | 47.8 | 5.0 |
| 11 | 1,200 | .100 | 77 | 31 | 9.4 | 44.0 | 4.2 |
| 18 | 1,300 | .040 | 73 | 1.2 | 8.4 | 51.0 | 5.3 |
| 17 | 1,300 | .047 | 71 | 2.5 | 7.5 | 50.5 | 5.9 |
| 57 | 1,300 | .047 | 76 | 3.9 | 9.0 | 50.6 | 4.9 |
| 71 | 1,300 | .047 | 78 | 2.6 | 7.3 | 52.5 | 6.3 |
| 15 | 1,300 | .053 | 82 | 6.6 | 6.1 | 51.0 | 7.4 |
| 77 | 1,300 | .053 | 86 | 6.2 | 4.7 | 53.6 | 10.0 |
| 16 | 1,300 | .060 | 80 | 8.9 | 6.7 | 50.0 | 6.6 |
| 80 | 1,300 | .060 | 87 | 9.6 | 5.1 | 52.6 | 9.1 |
| 52 | 1,300 | .066 | 84 | 15.7 | 6.5 | 49.8 | 6.7 |
| 58 | 1,300 | .066 | 78 | 14.8 | 8.8 | 50.1 | 5.1 |
| 20 | 1,300 | .100 | 85 | 32 | 6.6 | 46.0 | 6.1 |
| 39 | 1,300 | .200 | 92 | 78 | 6.4 | 24.1 | 3.3 |
| 59 | 1,400 | .040 | 69 | 1.7 | 10.4 | 51.4 | 4.4 |
| 60 | 1,400 | .047 | 73 | 3.2 | 9.6 | 52.6 | 4.8 |
| 61 | 1,400 | .053 | 85 | 6.7 | 5.3 | 52.6 | 8.7 |
| 62 | 1,400 | .060 | 87 | 11.6 | 4.8 | 51.6 | 9.5 |
| 52 | 1,400 | .066 | 84 | 15.7 | 6.5 | 49.8 | 6.7 |
| 63 | 1,400 | .100 | 91 | 44.3 | 4.1 | 41.0 | 8.8 |
| 64 | 1,400 | .200 | 92 | 80.3 | 5.9 | 22.5 | 3.4 |

Notes:

Roasts at 1,200° for 5.5 to 8 hr.; 90 percent of CO evolved in 1.5 to 3.5 hr.

Roasts at 1,300° for 6 to 7 hr.; 90 percent of CO evolved in 0.5 to 0.67 hr.

Roasts at 1,400° for 0.5 hr.; 90 percent of CO evolved in 8 to 20 min.

Increasing the amount of carbon from that necessary just to reduce the iron to 2.5 times this amount increases soluble chromium from 0.2 to 31 percent at 1,200°, from 1.2 to 32 percent at 1,300°, and from 1.7 to 44 percent at 1,400°. The tendency is for the amount of soluble iron also to increase with increasing carbon:chromite ratio, but only slowly, as compared with the increase in soluble chromium. The chromium:iron ratio of the residue appears to rise at first but later to fall as the excess of carbon is increased. The grade of product obtained, therefore, must be balanced against chromium

loss. If around 10 percent chromium loss is permissible then carbon:chromite ratios up to 0.060 are permissible (50 percent more carbon than necessary for iron reduction), but larger amounts of carbon are to be avoided, both from the viewpoint of grade of product and loss of chromium. Except for the reduction rate, there is very little, if any, advantage in reducing at temperatures above $1,300^{\circ}$.

Returning to table 3, a probable explanation now can be offered for the tendency of chromium losses to be higher with larger chromite particle sizes, in spite of the fact that only enough carbon for iron reduction was present. The larger particles are more difficultly penetrable by the reducing agent, and during most of the roasting period the rate of iron reduction must be slower, as shown by the time recorded for 90 percent of the carbon monoxide to be evolved. During the penetration period, the particles have a reduced shell of thickness increasing with time and an unreduced core of volume decreasing with time. If the particles are large enough for the penetration period to be long, the outer atoms are exposed to excess carbon for the long period. This is analogous, so far as the outer atoms are concerned, to a real excess of carbon, although, of course, the over-all effect is less pronounced. It would be expected, therefore, that the larger particles would produce proportionately less soluble iron and more soluble chromium than small particles subjected to a similar reducing roast. This appears to be the case, particularly at $1,300^{\circ}$.

Comparative Reducibility of Different Chromite Ores

Having established $1,300^{\circ}$ C. as the minimum temperature at which rapid reduction can be obtained, this temperature was selected for comparing the reducibility of four typical chromite ores. These ores were chosen partly because of their difference in composition. They represent as wide a variety as was readily obtainable, consistent with low silica content. They are typical of the clean concentrates that could be produced from various chromite or picotite deposits. It is seen from the analyses given earlier in this report that the chromium-to-iron ratio varies from 1.22 to 1.97; that the Cr_2O_3 content varies from 36 to 52.8 percent; and that the Al_2O_3 content varies from 4.8 to 26 percent. The Davis sample is one of the poorer grades of Montana picotites, the Benbow is a typical Montana ore, the Antelope was chosen for its unusually high Al_2O_3 content, and the Seiad is a concentrate from California. The last-named ore most nearly approaches "high-grade" specifications without further treatment.

Each ore was subject to reducing roasts with varying amounts of carbon. The results of these comparative tests are shown in table 6. In every instance a relatively small proportion of chromium is rendered acid-soluble by roasting mixtures containing low carbon:chromite ratios, but the amount of acid-soluble chromium rises rapidly with roast mixtures of higher carbon content. For each ore there is an optimum carbon:chromite ratio, which has been enclosed in parentheses in table 6. The optimum ratio is defined as that which gives the highest iron extraction consistent with a chromium loss of the order of 3 percent. This optimum ratio represents an excess of carbon above that required to reduce only the iron of the ore, an excess that in no case exceeds 20 percent. The reason for this will be discussed later in the report.

TABLE 6. - Results of tests with different chromite ores

| Run | Chromite sample | Temp., °C. | Ratio C:chromite | Fe removed, percent | Cr lost, percent | Ignited residue | | |
|--------|-----------------|------------|------------------|---------------------|------------------|-----------------|--|-------------|
| | | | | | | FeO percent | Cr ₂ O ₃ , percent | Cr:Fe ratio |
| 53.... | Davis | 1,300 | (0.053) | 76 | 2.7 | 10.5 | 50.0 | 4.2 |
| 54.... | | 1,300 | .061 | 80 | 6.8 | 9.2 | 48.3 | 4.6 |
| 55.... | | 1,300 | .068 | 78 | 10.8 | 10.4 | 47.9 | 4.1 |
| 56.... | | 1,300 | .076 | 81 | 16.8 | 8.8 | 46.6 | 4.7 |
| 88.... | Antelope | 1,300 | .035 | 72 | .7 | 9.3 | 45.8 | 4.3 |
| 87.... | | 1,300 | .040 | 86 | 1.5 | 4.6 | 46.6 | 8.8 |
| 86.... | | 1,300 | (.044) | 90 | 3.2 | 3.4 | 47.5 | 12.3 |
| 72.... | | 1,300 | .051 | 91 | 8.3 | 3.4 | 48.0 | 12.4 |
| 73.... | | 1,300 | .058 | 91 | 16.3 | 3.5 | 46.0 | 11.7 |
| 74.... | | 1,300 | .066 | 94 | 23.1 | 2.4 | 43.8 | 16.1 |
| 75.... | | 1,300 | .073 | 94 | 28.9 | 2.8 | 46.9 | 15.0 |
| 76.... | | 1,300 | .110 | 95 | 61.6 | 2.5 | 25.6 | 9.0 |
| 85.... | Seiad | 1,300 | .035 | 63 | 1.3 | 11.2 | 65.8 | 5.2 |
| 84.... | | 1,300 | .040 | 69 | 2.1 | 9.8 | 67.4 | 6.1 |
| 83.... | | 1,300 | (.044) | 73 | 3.0 | 8.3 | 68.0 | 7.2 |
| 66.... | | 1,300 | .052 | 82 | 6.3 | 6.0 | 69.6 | 10.2 |
| 67.... | | 1,300 | .059 | 89 | 12.7 | 3.6 | 69.0 | 16.7 |
| 68.... | | 1,300 | .067 | 88 | 15.9 | 4.0 | 67.8 | 14.7 |
| 69.... | | 1,300 | .074 | 90 | 20.7 | 3.8 | 67.0 | 15.9 |
| 70.... | | 1,300 | .111 | 89 | 38.2 | 4.9 | 61.6 | 11.0 |
| 18.... | Benbow | 1,300 | .040 | 73 | 1.2 | 8.4 | 51.0 | 5.3 |
| 17.... | | 1,300 | (.047) | 71 | 2.5 | 7.5 | 50.5 | 5.9 |
| 15.... | | 1,300 | .053 | 82 | 6.6 | 6.1 | 51.0 | 7.4 |
| 16.... | | 1,300 | .060 | 80 | 8.9 | 6.7 | 50.0 | 6.6 |
| 52.... | | 1,300 | .066 | 84 | 15.7 | 6.5 | 49.8 | 6.7 |
| 20.... | | 1,300 | .100 | 85 | 32 | 6.6 | 46.0 | 6.1 |

Notes:

Davis, -200 mesh, 1-hour reducing roast.

Antelope and Seiad, -100 mesh, 2-hour reducing roast.

Benbow, -200 mesh, 6-hour reducing roast.

Optimum C:chromite ratios as enclosed in parentheses.

Particular attention is called to the fact that with all four ores the amount of soluble chromium is less than 3.2 percent, whereas at least 70 percent of the iron has been rendered acid-soluble by reduction with this optimum amount of carbon. As the carbon:chromite ratio is increased above this value, each ore shows a marked rise in the amount of acid-soluble chromium accompanied by a relatively small increase in the amount of extractable iron. This series of experiments brings out the importance of careful control of the carbon:chromite ratio of the roast mixture if minimum reduction consistent with high iron removal is desired.

Figure 2 shows the effect of the carbon:chromite ratio upon the amount of acid-soluble iron and chromium. For each ore, there is a critical ratio at which the soluble-chromium curve breaks sharply upward and at which the amount of extractable iron is high, though not quite at the maximum value. The abscissas of this graph are the values used throughout this report to express the carbon content of the original carbon-chromite roast mixtures and are numerically equal to the weights of carbon per unit weight of chromite ore. The ordinates of figure 2 are a measure of the amount of acid-soluble iron or chromium in the roast products and are expressed in percentage of the total amount present in these products. The values in the graph are taken directly from columns 4, 5, and 6 of table 6.

The grade of the ignited acid-leached residue is shown in the last three columns of table 6, and the Cr_2O_3 contents of these residues are plotted in figure 3 against carbon:chromite ratios of the roast mixtures. Both of these show that as the amount of carbon in the roast mixtures is increased the grade of the product improves up to a certain maximum value, beyond which it declines. The Cr_2O_3 content of the ignited leached residue is close to its maximum figure at the same critical carbon:chromite ratio as was enclosed in parentheses in table 6.

Therefore, for all four ores, it has been shown that this optimum carbon content of the roast mixture is advantageous from both the standpoint of chromium loss and the grade of the acid-leached product.

The notes accompanying table 6 indicate that the various ores were of different grain size and were roasted at the same temperatures but for different lengths of time. However, it is considered that these tests are comparable, as other experiments, mentioned previously, have shown that similar mixtures reduced for 0.5 hour, 1 hour, 2 hours, or 6 hours at $1,300^\circ$ yield virtually the same amount of extractable metals, and that there is very little difference in the behavior of chromite ore of finer particle sizes, whether they be -200, -100, or -65 mesh.

These tests have demonstrated that chromites of greatly different compositions, when reduced with careful control of carbon content, yield products from which a large portion of the iron can be extracted with only a small loss of chromium. Comparison of the Seiad (4.8 percent Al_2O_3) with the Antelope (26 percent Al_2O_3) curves in figure 2 shows that there is no appreciable difference in the shape of the curves attributable to the Al_2O_3 content of the ore.

Another interesting aspect of table 6 and figure 2 is that the limiting percentage of extractable iron seems to be different for the different ores. As the carbon content is increased, each ore tends to produce a larger amount of extractable iron until a limiting value is approached. No iron extractions above 87 percent were obtained from either the Benbow or Davis samples, whereas soluble iron from the Seiad sample tended to approach 90 percent and that from the Antelope ore approached 95 percent. The analyses of these samples offer no explanation of the variation of this maximum limit on the

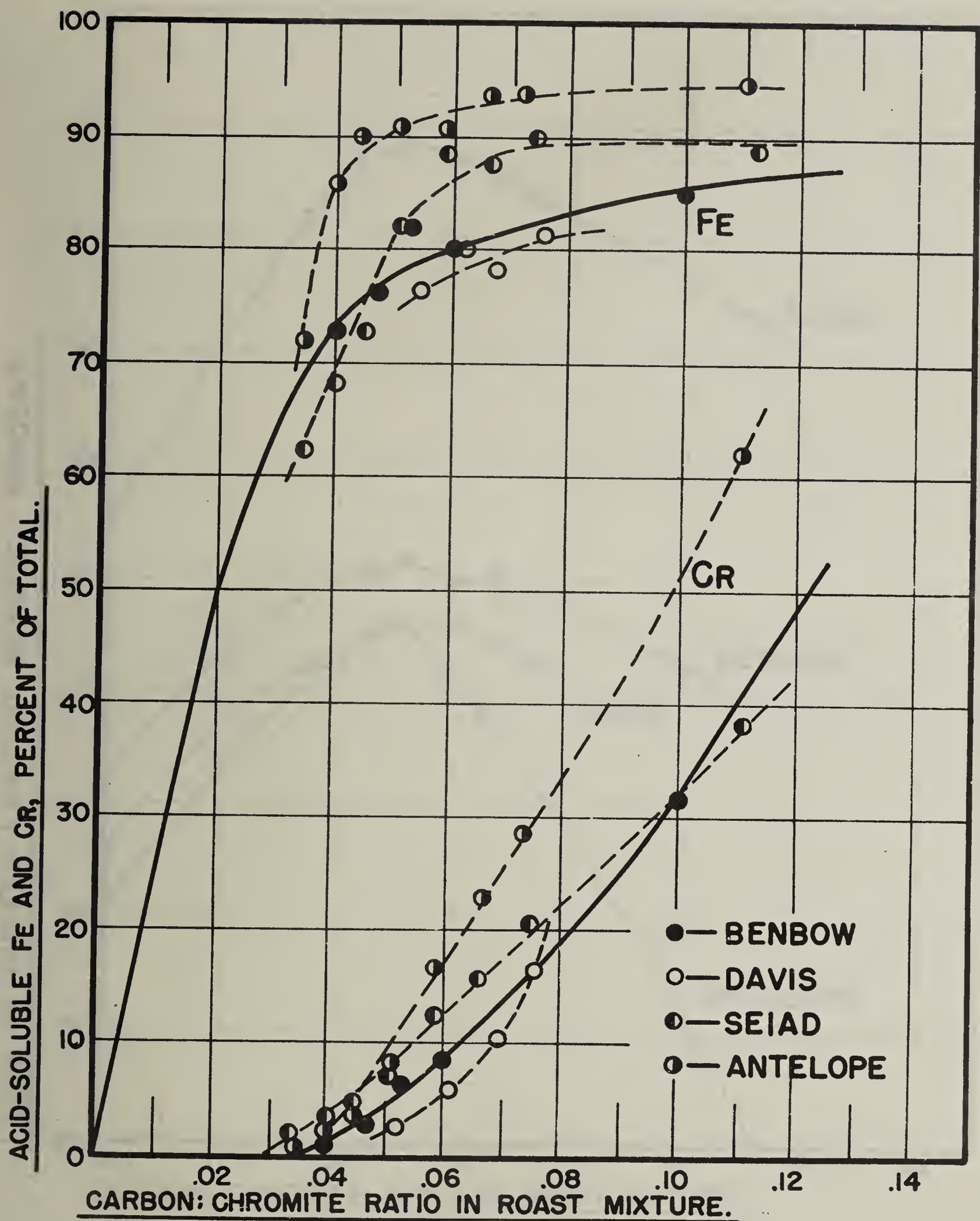


FIGURE 2.- Acid-soluble iron and chromium as a function of carbon:chromite ratio.



Figure 1. A graph showing the relationship between the percentage of humus in soil and the percentage of water in soil. The curves show that as the percentage of humus increases, the percentage of water in the soil also increases. The curves are labeled with the names of the different soil types: White Loch, Ester, Davis, and Dewey.

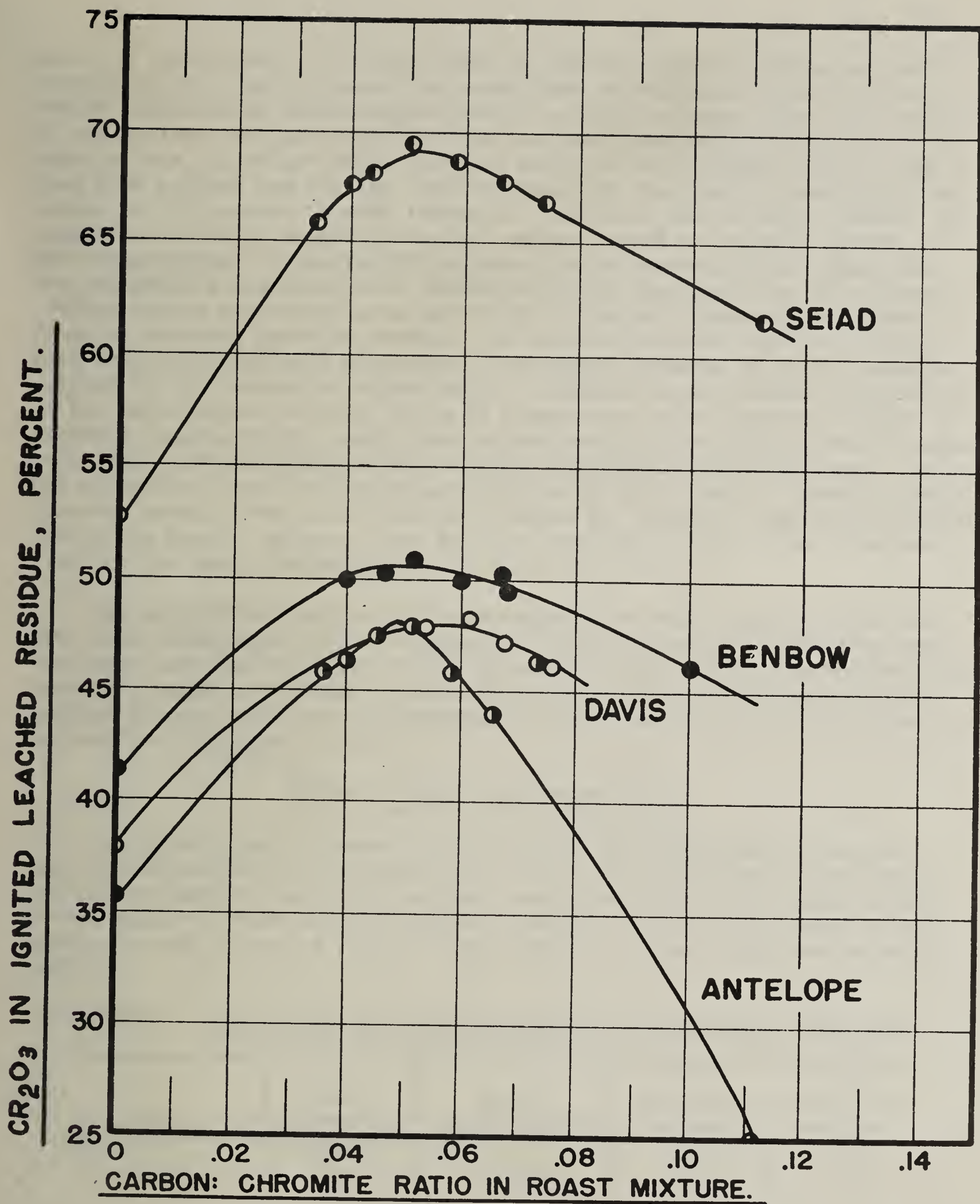


FIGURE 3.- Grade of leached residue as a function of carbon:chromite ratio.

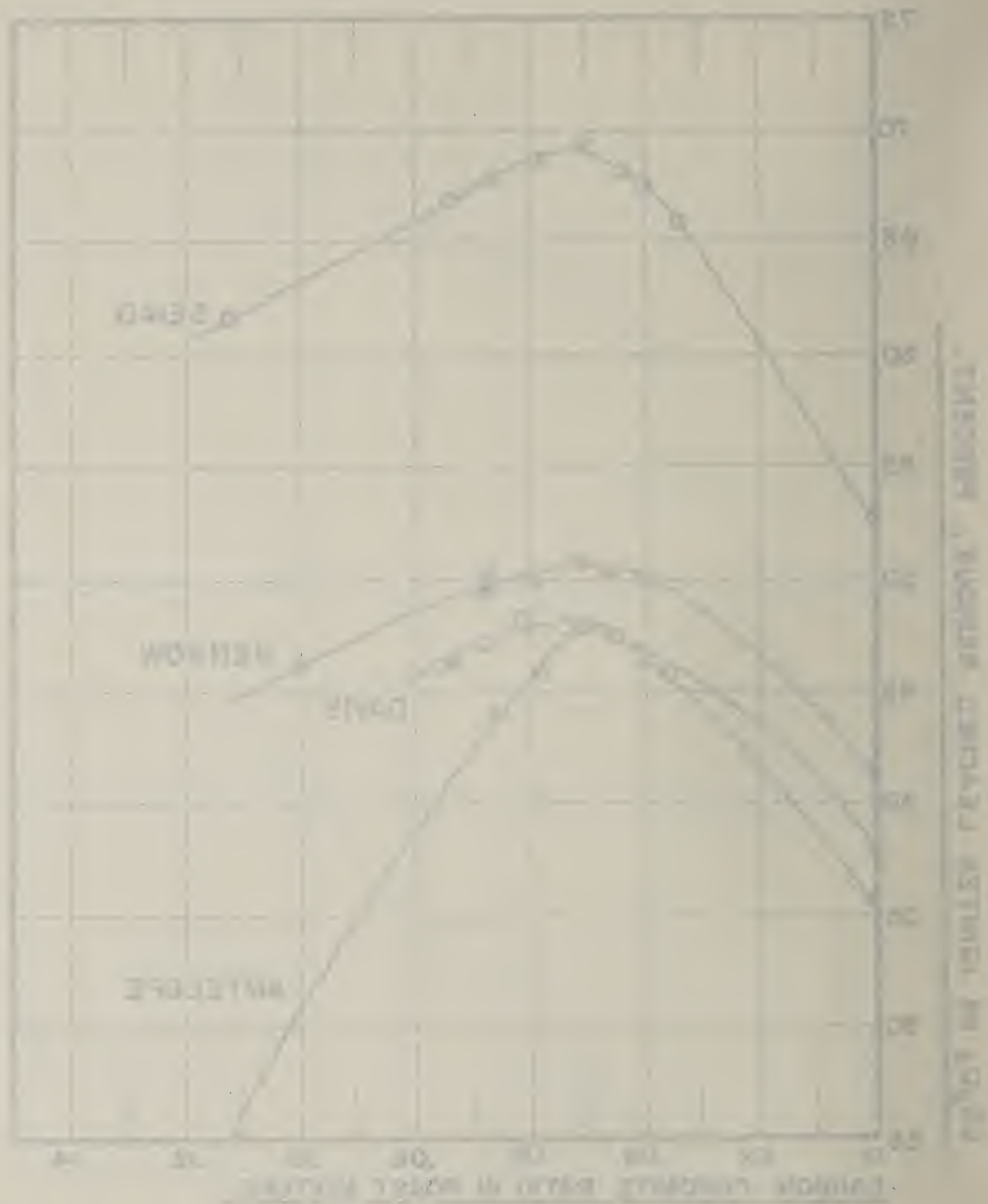


Figure 1. Thermal stability index vs. thermal stability index in 100°C.

basis of impurities. It is difficult to believe that the remaining (acid-insoluble) iron can be present in a compound of sufficient stability to resist reduction at these temperatures. As will be shown later, the volume of gas evolved indicates that all the iron has been reduced by carbon. If this is true, it is not clear why more iron can be extracted from one ore than from another and why the limiting value of iron removal should not be closer to 100 percent in each instance. This much can be said, however, if reduction occurs at temperatures that permit little or no grain growth of the reduced metal or recrystallization of the unreduced oxides, then the reduced metal atoms might be in essentially the same position after reduction as before reduction, with only their attendant oxygen atoms removed from the original chromite crystal. If such is the case, the leach acid must travel through each particle to its center by means of small channels created by the removal of oxygen atoms. A glance at the atomic arrangement of the cubic spinel lattice, which is isomorphous with chromite, chrome-picotite, and hercynite, shows how devious would be the path of this leaching acid if no recrystallization had occurred during the reduction roast. It is not surprising, therefore, that some of the central atoms of iron from each chromite particle may be difficult to remove by leaching, even though reduced during the roast. However, this does not explain why more iron is removed from one ore than from another.

The significant results of these comparative tests are (1) conditions have been found permitting the removal of over 70 percent of the iron content and less than 4 percent of the chromium content of all the ores studied thus far; regardless of their composition, and (2) each ore has yielded a leached residue that passes "high-grade" specifications for Cr_2O_3 content and ratio of chromium to iron.

Effect of SiO_2 upon Reducibility

Two experiments on Benbow ore at $1,300^\circ$, each comprising a pair of tests, were performed to determine the effect of silica upon reducibility. The carbon:chromite ratio for one pair was 0.040 and for the other 0.060. To one member of each pair was added an amount of -200 silica equal to 10 percent of the weight of the ore. The results of these tests are shown in table 7.

TABLE 7. - Results of tests showing effect of silica upon reduction

| Run | Ratio C:chromite | Ratio SiO_2 :chromite | Fe extracted, percent | Cr extracted, percent |
|----------|---------------------|-----------------------------------|-----------------------------|-----------------------------|
| 40 | 0.040 | 0 | 64.5 | 1.9 |
| 41 | .040 | 0.100 | 60.6 | 1.4 |
| 80 | .060 | 0 | 87 | 9.6 |
| 78 | .060 | 0.100 | 90 | 10.0 |

The products from these 1,300° roasts showed only a minor amount of sintering and could be broken up readily upon cooling. There is only a relatively small difference in the amount of extractable iron that might be attributed to the presence of silica. In fact, the above pairs may be considered checks, because even identical roast mixtures sometimes yield larger variations in amount of extractable iron than is shown in table 7. Compare, for example, the soluble-iron values for runs 17, 57, and 71 or 16 and 80 in table 5.

It must be emphasized, however, that the tests in table 7 were made with synthetic mixtures of ore and pure silica. In the chromite concentrates, at least some of the silica content probably occurs not as pure silica but as complex silicates that conceivably may have a melting point low enough actually to melt and flow around the chromite particles during roasting, thereby rendering their iron content impervious to the action of leaching acid. The data obtained with natural ores are not conclusive with regard to this point. It can be stated only that silica in amounts up to 6 percent (Antelope) does not seem to have any harmful effect upon reduction and subsequent leaching. In fact, the ore with the highest content of both alumina and silica gave the largest percentage of extractable iron when reduced with the optimum amount of carbon.

Residual Carbon in the Roast Products

In each of the earlier reducing roasts, the amount of gas evolved was measured and the volume of carbon monoxide (after correcting for hydrogen) was used as a measure of reaction rate. These figures also can be used to calculate roughly the carbon content of the roast products, by subtracting the weight of carbon evolved as carbon monoxide from the weight of carbon originally mixed with chromite and then dividing this result by the weight of chromite after correcting for weight lost by oxygen removal.

This has been done in table 8 for roasts at 1,200°, 1,300°, and 1,400°, in which -200 mesh Benbow ore was used in conjunction with varying carbon:chromite ratios, as shown in column 3. In column 4 are recorded the amounts of carbon monoxide evolved, expressed as percentage of the total theoretical amount that could be formed by the conversion of all the carbon to carbon monoxide. In column 5, the residual carbon in the roast products has been calculated from the carbon monoxide data. Column 6 shows the results of actual combustion analyses of three of the roast products. In the last column are listed the molal ratios of carbon to metal in the roast products, based upon the total amount of acid-soluble iron and chromium and on the calculated carbon contents.

The molal ratios of carbon to metal vary between 0.34 and 0.61 for the 1,200° products, between 0.16 and 0.44 for those produced at 1,300°, and between 0.06 and 0.26 in the 1,400° roast products. In general, two trends are apparent: (1) For a given roasting temperature, an increase in the amount of soluble metal is accompanied by an increased carbon-to-metal ratio, and (2) for a given roast mixture, lower carbon-to-metal ratios are produced as the roasting temperature is increased.

TABLE 8. - Calculations of residual carbon contents of roast products

| Run | Temp. of roast, °C. | Ratio C:chromite | CO evolved, percent of theoretical | C in roast product, (calc.) percent | C in roast product, (analysis) percent | Molal ratio, carbon to reduced metal in product |
|--------|---------------------|------------------|------------------------------------|-------------------------------------|--|---|
| 5.... | 1,200 | 0.040 | 68 | 1.30 | 1.26 | 0.53 |
| 9.... | 1,200 | .040 | 68 | 1.30 | | .50 |
| 13.... | 1,200 | .047 | 79 | 1.01 | | .34 |
| 12.... | 1,200 | .053 | 76 | 1.30 | | .38 |
| 14.... | 1,200 | .060 | 71 | 1.78 | | .49 |
| 10.... | 1,200 | .067 | 71 | 1.99 | | .47 |
| 11.... | 1,200 | .100 | 65 | 3.68 | | .61 |
| 18.... | 1,300 | 0.040 | 87 | .52 | 0.40 | .16 |
| 17.... | 1,300 | .047 | 88 | .56 | | .16 |
| 15.... | 1,300 | .053 | 88 | .65 | | .16 |
| 16.... | 1,300 | .060 | 83 | 1.03 | | .24 |
| 20.... | 1,300 | .100 | 72 | 2.88 | | .44 |
| 30.... | 1,400 | 0.040 | 96 | .16 | 0.34 | .06 |
| 31.... | 1,400 | .047 | 92 | .38 | | .12 |
| 32.... | 1,400 | .053 | 92 | .42 | | .11 |
| 33.... | 1,400 | .060 | 89 | .66 | | .15 |
| 34.... | 1,400 | .067 | 88 | .81 | | .18 |
| 35.... | 1,400 | .100 | 82 | 1.84 | | .26 |

Several mixed iron and chromium carbides are mentioned in the literature, $(\text{Cr,Fe})_3\text{C}_2$, $(\text{Cr,Fe})_7\text{C}_3$, $(\text{Cr,Fe})_3\text{C}$, and $(\text{Cr,Fe})_4\text{C}$, of which the carbon-to-metal ratios are 0.67, 0.43, 0.33, and 0.25, respectively. The products of the 1,200° roasts contain mixed carbides containing higher carbon:metal ratios, whereas those at 1,300° contain less carbon per weight of reduced metal. Those produced at 1,400°, except the last one, contain less carbon than corresponds to the lowest known carbide, and therefore must contain, in addition, metallic iron and chromium.

Despite the approximate nature of the calculations, these data demonstrate that the conclusions reached by the equilibrium study, discussed later, are generally true of the roasts; or that the lower the temperature of the roast, the higher is the carbon content of the roast products; and that above 1,200° virtually all of this residual carbon is combined as metallic carbides. It is recognized that with larger carbon than was used for these experiments there may be some residual carbon that has not reacted at all. This, however, does not invalidate the general conclusions reached concerning the temperature trends of carbide formation.

It was mentioned earlier in this report that the optimum amount of carbon for each of the ores was found to exceed that required for the reduction of FeO to Fe . The reason for this excess (10 to 30 percent) now becomes apparent; enough carbon must be added to produce a certain amount of carbide

as well as to reduce the FeO. There was no evidence (except in one roast, run 11) of any residual carbon that was not combined as carbides of iron and chromium. Therefore, it is concluded that (1) if the roast is conducted at 1,200°, an excess of 20 to 30 percent carbon over the theoretical amount must be added; (2) at 1,300°, an excess of 10 to 20 percent must be used; (3) at 1,400°, less than 10 percent excess is necessary. Thus, there is a higher utilization of carbon for reduction of oxides at higher temperatures than at lower temperatures.

Effect of Back-Oxidation upon Roast Products

Roast products from several runs not recorded in this report produced less soluble iron than was anticipated. It was suspected that the reduced iron had accidentally been partly oxidized during the cooling process, thereby converting some of the iron back to an acid-insoluble form. This was confirmed by several tests in which roast products were deliberately heated in air for short periods. Three roast products of different original carbon:chromite ratios were oxidized at 900° in air in open dishes. They were then leached with acid of the same strength as used in former leaches. The effects of these oxidizing treatments upon the amount of acid-soluble metals are summarized in table 9.

TABLE 9. - Results of back-oxidation tests

| Description of sample | | Fe extracted, percent | Cr extracted, percent |
|---|--------------------------|-----------------------------|-----------------------------|
| Run No. 18 | C:chromite ratio = 0.040 | 69 | 1.7 |
| Same sample after 2 min. oxidation at 900° C. | | 7.4 | .2 |
| Run No. 60 | C:chromite ratio = 0.047 | 74 | 3.2 |
| Same sample after 5 min. oxidation at 900° C. | | 12.2 | .1 |
| Run No. 75 | C:chromite ratio = 0.073 | 94 | 28.9 |
| Same sample after 5 min. oxidation at 900° C. | | 80 | 17.2 |

The effect of this oxidizing roast is seen by comparing the amounts of acid-soluble metal before and after the treatment. The first sample, a 0.040 carbon:chromite roast, shows the greatest effect. A 2-minute exposure to oxidizing environment at 900° lowered the amount of acid-soluble iron from 69 percent to 7.4 percent, with a corresponding lowering of the amount of soluble chromium. The effect on the second sample, a 0.047 carbon:chromite roast, was only slightly less severe. The third sample, a 0.073 carbon:chromite roast, showed relatively little effect. It is obvious that the least oxidized sample had a relatively high original carbon:chromite ratio and therefore a relatively large amount of acid-soluble chromium. That this metal should resist oxidation more effectively than a low chromium-containing metal is to be expected, because resistance to oxidation at high temperatures is one of the most important properties of commercial high-chromium steels.

In summarizing these tests, it may be said that (1) roast products of low carbon:chromite ratios, if given the opportunity, oxidize rapidly, thereby lowering the amount of extractable iron, and (2) roast products of relatively high carbon:chromite ratios are less affected by oxidation because of the protective action of chromium in the reduced metal.

Comparison of Hot and Cold Sulfuric Acid Leaching

It has been suggested that cold acid leaches remove less chromium from the roast products than hot acid, whereas only slightly less iron is extracted in the cold leach than in the hot leach. A single series of comparisons was made of four samples roasted with varying carbon:chromite ratios to determine the effect of this ratio upon the amount of iron and chromium extracted by hot and cold acids. One strength of hot acid (10 percent by volume) was used, the leach having been identical in time and the extraction values identical with those recorded earlier in the report. Two strengths of cold (room-temperature) acid were used - 10 percent by volume and 25 percent by volume. The leaching times and amount of extractable iron and chromium are recorded in table 10.

TABLE 10. - Results of tests with hot and cold leaching acid

| Run | Ratio C:chromite | Leaching agent | Leaching time, hr. | Fe extracted, percent | Cr extracted, percent |
|---------|---------------------|---------------------------|--------------------------|-----------------------------|-----------------------------|
| 77..... | 0.053 | Hot 10 percent H_2SO_4 | 1 | 86 | 6.2 |
| | | Cold 25 percent H_2SO_4 | 16 | 88 | 6.2 |
| | | Cold 10 percent H_2SO_4 | 2 | 88 | 5.8 |
| 58..... | 0.066 | Hot 10 percent H_2SO_4 | 1 | 78 | 14.8 |
| | | Cold 25 percent H_2SO_4 | 16 | 72 | 11.0 |
| | | Cold 10 percent H_2SO_4 | 2 | 60 | 2.9 |
| 20..... | 0.100 | Hot 10 percent H_2SO_4 | 1 | 85 | 32.1 |
| | | Cold 25 percent H_2SO_4 | 16 | 56 | 7.1 |
| | | Cold 10 percent H_2SO_4 | 2 | 49 | 4.1 |
| 64..... | 0.200 | Hot 10 percent H_2SO_4 | 1 | 92 | 80.3 |
| | | Cold 25 percent H_2SO_4 | 40 | 18 | 2.9 |
| | | Cold 10 percent H_2SO_4 | 40 | 21 | 2.6 |

The results indicate that for products roasted with low carbon:chromite ratios there is very little, if any, difference between the action of hot or cold acid upon either iron or chromium. As the carbon:chromite ratio is increased, the solubility of chromium in cold acid decreases markedly, particularly in the short (2-hour) treatment with dilute acid. At the same time, the solubility of the iron in cold acid also decreases, the effect being more pronounced, the higher the ratio. This effect probably can be attributed to solubility of chromium carbide in iron carbide, which has been reported frequently in the literature. This iron carbide containing

various proportions of chromium carbide is formed during the reducing roast. The solubility of the mixed carbide in cold acid appears to depend upon its chromium content, being more soluble as the chromium decreases. The figures in table 10 illustrate this point. The first sample has a relatively small reduced chromium content and consequently showed about the same extractability of iron and chromium with cold acid as with hot acid. The second, third, and fourth samples contain progressively greater amounts of reduced chromium, and a progressively less proportionate amount of chromium was extracted by cold 10 percent acid or by cold 25 percent acid. At the same time, the amount of iron extracted also decreased. The results for the fourth sample are particularly marked, as cold 10 percent acid or cold 25 percent acid extracted only a relatively small part of the reduced iron and chromium in 40 hours.

The grade of the leached residues has been calculated, though not recorded in table 10. The first residue of table 10 from the cold dilute acid treatment is similar to that from the hot acid treatment, both having approximately 53 percent Cr_2O_3 and a Cr:Fe ratio close to 10. The second sample, leached with hot acid, yields a residue containing 50 percent Cr_2O_3 and a Cr:Fe ratio of 5.1, but when leached with cold dilute acid produces a residue for which the Cr:Fe ratio is only 3.2. The third sample gives a hot acid leach residue containing 46 percent Cr_2O_3 and a ratio of 6.1, whereas the residue from the cold dilute acid leach contains 49.7 percent Cr_2O_3 and a Cr:Fe ratio of only 2.54. The fourth sample produced unacceptable residues from both hot and cold leaches.

To summarize, these tests indicate that although the reduced chromium is not appreciably soluble in cold acid, a certain portion of the reduced iron also fails to dissolve in this acid, the amount increasing as the amount of reduced chromium increases. Further work should supplement these tests if it is desired to separate iron from chromite by cold-acid leaching of roasts made with high carbon:chromite ratios.

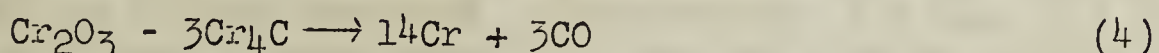
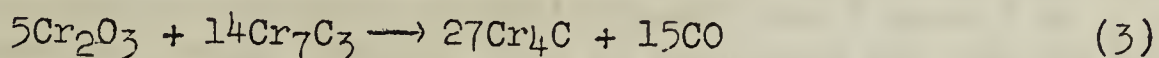
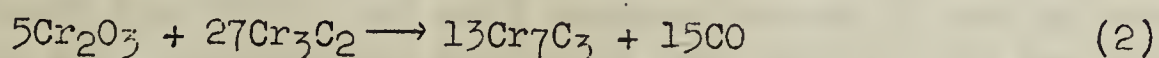
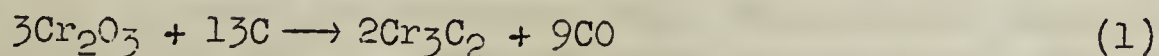
SOME THEORETICAL ASPECTS OF THE SELECTIVE REDUCTION OF CHROMITE

Reduction Equilibrium Measurements

To illuminate the reaction steps that occur during the reduction of chromite ore, a series of equilibrium measurements was undertaken. These measurements were made by a method developed for a thermodynamic study of the pure carbides of chromium, which were investigated just prior to the present work.^{4/} Most of the latter study is beyond the scope of this report, but certain aspects of it help to explain the presence of acid-soluble chromium in the chromite roast products and to clarify the complicated stoichiometry of the reduction of chromite.

^{4/} Boericke, F. S., Equilibria in the Reduction of Chromic Oxide by Carbon, and Their Relation to the Decarburization of Chromium and Ferrochrome: Bureau of Mines Rept. of Investigations 3747, 1944, 34 pp.

Experiments^{4/} have shown that if just enough carbon is added to pure chromic oxide to reduce it to metallic chromium, the reduction takes place in four well-defined steps:



Steps (1) and (2) take place at measurable rates at temperatures below 1,300°. The last two steps, (3) and (4), can be carried to completion at 1,400° only by the removal of carbon monoxide by evacuation or flushing with inert gas.

Past experience with these reactions has shown that they are reversible, and therefore that there is a definite relationship between temperature and carbon monoxide pressure when equilibrium has been established. An apparatus was built that permitted a sample of oxide and carbon or oxide and carbide to be held at constant temperature until the carbon monoxide pressure came to equilibrium, and which also permitted the measurement of the pressure and the analysis of the gas for its carbon monoxide content. This apparatus, described elsewhere,^{5/} was used for investigating the equilibrium carbon monoxide pressures encountered during the reduction of chromite ore. An amount of carbon sufficient to reduce both the iron and chromium to metal was mixed with Benbow concentrates (-200 mesh), and the mix was held at various temperatures to study the reactions that took place. The carbon used in this experiment was a sample of "Norblack" that had been treated at 1,000° with chlorine to remove the small amount of hydrogen.

The results bring out several interesting points. The primary reaction, the reduction of iron, was found to be irreversible, as shown by the fact that the pressure of carbon monoxide could be raised by increasing the temperature, but could not be lowered by cooling even to room temperature. The reaction evolved carbon monoxide slowly at temperatures as low as 700°, but the rate was measurable at 1,000°. A measured amount of gas was removed periodically from the system and analyzed. In addition to carbon monoxide, a small amount of hydrogen was found that presumably came from the chromite (possibly as occluded water) and that decreased as reduction proceeded. Periodic removal of gas was continued until the total amount corresponded roughly to the reduction of all the iron of the sample. Pressure measurements up to this point indicated no tendency for the reaction to reverse by lowering the reaction temperature.

After the iron was reduced, the carbon began to reduce the Cr_2O_3 of the chromite, producing carbon monoxide pressures that were dependent upon the temperature. These ensuing reactions are reversible and take place in

^{5/} Work cited in footnote ^{4/}.

well-defined steps, producing definite pressure-temperature relationships. The results are shown in figure 4, in which the equilibrium pressure of carbon monoxide in centimeters of mercury are plotted against the corresponding centigrade temperature. The pressures are shown by circles and numbered in the order in which they were measured. After each pressure measurement, a known volume of gas was removed from the system and analyzed for carbon monoxide and the pressure was corrected accordingly. The solid lines A, B, C, and D of figure 4 are the equilibrium pressure-temperature relationships that occur during the reduction of pure chromic oxide, according to equations (1), (2), (3), and (4), respectively. They are plotted on the same figure to show the analogy between the reduction reactions of pure Cr_2O_3 and those occurring with chromite.

In the light of experience with pure chromic oxide, and with due consideration of the total amounts of carbon monoxide that were removed from the system periodically between pressure measurements, the results may be interpreted as follows:

1. The reduction of FeO in chromite takes place irreversibly at temperatures below $1,100^\circ$.
2. Points 3, 4, and 5 correspond to the reduction of Cr_2O_3 of the chromite to Cr_3C_2 , analogous to reaction (1).
3. Point 7 corresponds to the decarburization of Cr_3C_2 to Cr_7C_3 by more Cr_2O_3 , analogous to reaction (2).
4. Points 8 and 9 correspond to reaction (3).
5. Point 10 corresponds to the conversion of the lowest carbide of chromium, Cr_4C , to metal, analogous to reaction (4).

All the numbered points are slightly higher than the corresponding solid lines. It is not surprising that chromite should produce equilibrium pressures different from those of pure chromic oxide. The activity of chromic oxide in combination with the other oxides of chromite is different from that of pure chromic oxide, and the activity of the carbides of chromium, or of chromium metal, when combined with iron carbide or iron cannot be equal to that of the corresponding pure chromium carbides or chromium, as the case may be. It would require a surprising compensation of the effects of altered activities to produce equilibria falling exactly upon the curves for pure chromic oxide.

Points 1, 2, and 6 do not bear the same relationship to the solid lines as do the other equilibrium points. The first two were obtained after the irreversible reduction of FeO but before reaction (1) was proceeding smoothly. These two transitory points appear to be true equilibria but produce pressures farther removed from curve (A) than points 3, 4, and 5. Two possible explanations can be given for this effect. First, that there is a reaction between iron carbide and chromic oxide, and, second, that reaction (1) is

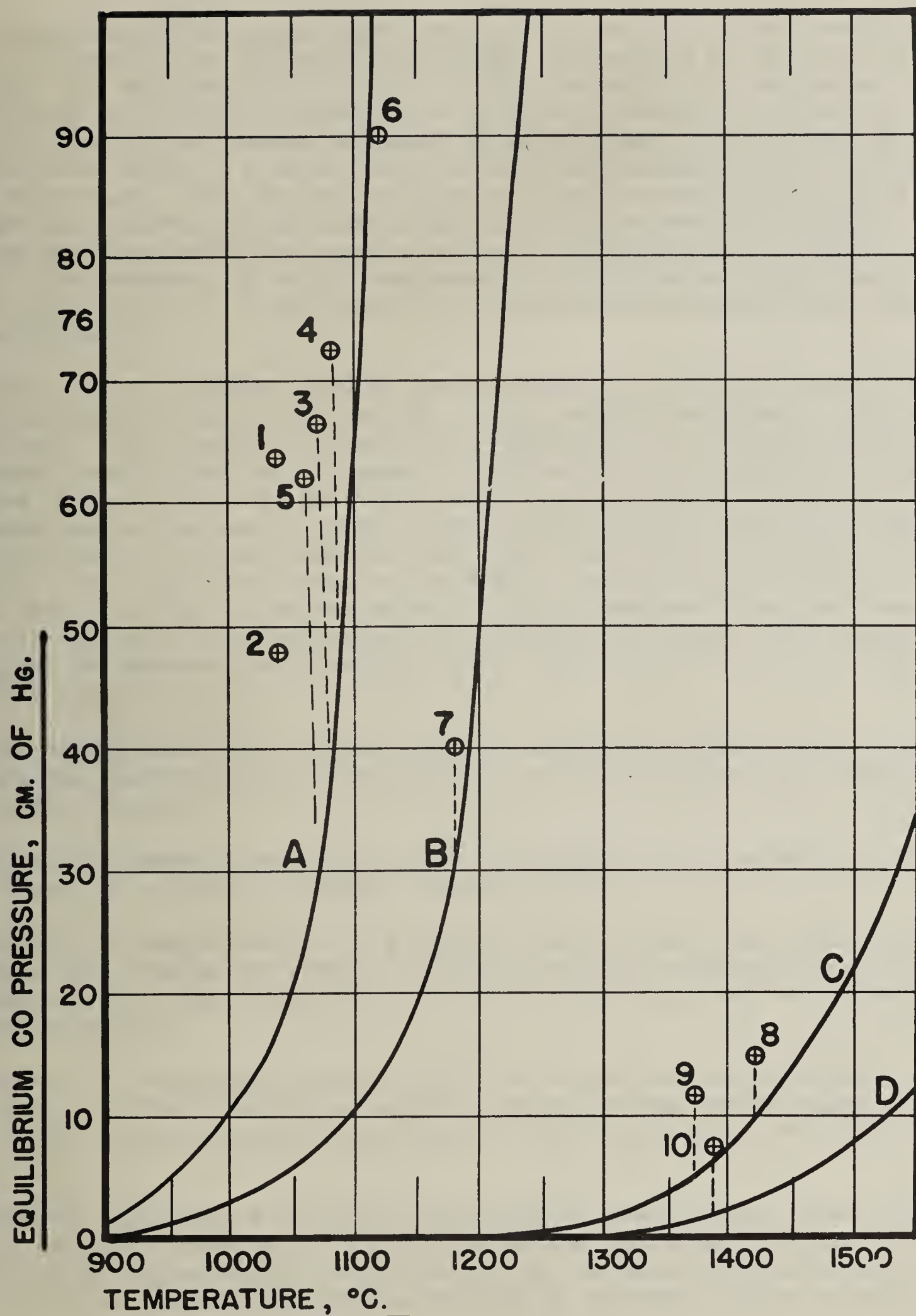


FIGURE 4.- Equilibrium carbon monoxide pressure-temperature relationships. (Numbered points refer to chromite; curves refer to pure Cr_2O_3 .)

Fig. 1. Dependence of the rate of polymerization on the concentration of the initiator.



where k_p is the rate constant for the propagation reaction, k_t is the rate constant for the termination reaction, k_d is the rate constant for the decomposition of the initiator, and k_i is the rate constant for the initiation reaction.

proceeding during these measurements but that the activity of the reactant (Cr_2O_3 in chromite) or of the product (Cr_3C_2) is changing as the reaction proceeds. The explanation for point 6 is well known and has been shown to be true with the reactions between pure oxide and carbides of chromium. During the transition between one reaction and the next ((1) and (2), in this instance) there is a small range in which the pressures drift from one curve to the next. This may be explained by a small mutual solubility of the two carbides. During these transitional periods, the reactions are more sluggish and less readily reversible because of the deficiency of either a product or a reactant, or both. Therefore, as with pure materials, these transitional points 1, 2, and 6 must be disregarded when interpreting the data of figure 4.

There is one reaction that was not clarified by the equilibrium measurements, but which is known to occur during the reduction of chromite with excess carbon. This reaction concerns the formation of iron carbide and its subsequent decarburization. A summary of carbon monoxide evolution data and analyses of roast products, described earlier in connection with table 8, indicates that reductions at $1,200^\circ$ produce iron carbide, whereas much of the iron reduced at higher temperatures, $1,300^\circ$ and $1,400^\circ$, is present as metallic iron. Equilibrium data do not reveal whether the decarburization of the iron occurs as a distinct reaction step or whether it proceeds during the entire stepwise decarburization of the chromium carbides. The answer to this question, however, has little practical significance if the over-all effect is known to exist.

The significant facts learned from the equilibrium study are the order in which the following general reactions occur and the approximate temperature range of each:

First, at temperatures below $1,100^\circ$ iron oxide of the chromite is reduced slowly by carbon, but chromium oxide is not.

Second, at temperatures in the neighborhood of $1,100^\circ$ the oxides of both iron and chromium are reduced slowly to carbides of these metals, and at temperatures in the neighborhood of $1,200^\circ$ these reactions take place relatively rapidly.

Third, at temperatures above $1,200^\circ$ the decarburization of chromic carbide, Cr_3C_2 , to the intermediate carbide, Cr_7C_3 , by some of the remaining Cr_2O_3 of the ore may proceed slowly, and at $1,300^\circ$ this reaction is more rapid.

Fourth, reduction of chromite with carbon at temperatures above $1,400^\circ$ permits the above three stages to take place with great rapidity, but even at these high temperatures, though the iron may be completely decarburized, there is little tendency for decarburization of chromium carbide to metal.

Thus, the higher the roasting temperature, other factors being equal, the less carbon as carbides there will be in the roasted product and the more metal there will be rendered acid-soluble per unit weight of carbon in the original roast mixture.

Some Back-Oxidation Reactions

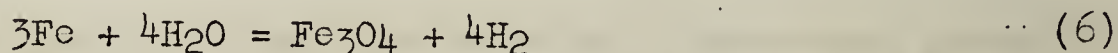
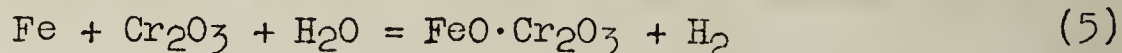
Back-oxidation of reduced roast products by air was discussed earlier in this report. Attention now will be given to the possibilities of back-oxidation by water and carbon dioxide.

The furnace gas in internally heated equipment for selective reduction of chromite, such as a rotary kiln, is composed essentially of carbon dioxide, carbon monoxide, water, hydrogen, and nitrogen, being the resultant product of combustion of fuel and reduction of chromite.

The reduced iron in the roast product is considered to be present, under usual conditions, as a mixed carbide of iron and chromium or as a mixed carbide of iron and chromium plus metal. There are no thermochemical data for such mixed carbides, and a choice must be made between writing back-oxidation reactions involving pure iron carbide (Fe_3C) and writing back-oxidation reactions involving pure iron. For the present discussion, the latter course is selected for two reasons. First, the best available heat of formation value of Fe_3C is admitted to have a high probable uncertainty. Second, using available figures for Fe_3C , it may be shown that this substance is oxidizable to oxide by lower concentrations of carbon dioxide and water than are required for oxidation of iron. This assumes that the oxidation of Fe_3C to oxide occurs in one step. If it occurs in two steps, first to iron and then to oxide, only the second step would be of importance from the present viewpoint. On the other hand, it appears probable, at least, that the oxidation of a mixed carbide might require somewhat greater concentrations of carbon dioxide and water than is necessary for oxidation of iron. It would appear, therefore, that the course to be followed has a good chance of being the middle road.

For reactions not involving re-formation of chromite, it will be considered that magnetite is the oxidation product. However, it is not implied that an intermediate step, involving formation of ferrous oxide, may not occur. Free ferrous oxide is largely acid-soluble and its formation would not be deleterious unless it made solid solutions with other ingredients. Magnetite is relatively insoluble in the leaching media for selectively reduced chromite and is therefore undesirable.

The following reactions with water are considered first:



Equilibrium constants of these reactions may be evaluated readily from available data. 7/, 8/, 9/, 10/, 11/ Results are listed in table 11.

TABLE 11. - Equilibrium constants of reactions of water

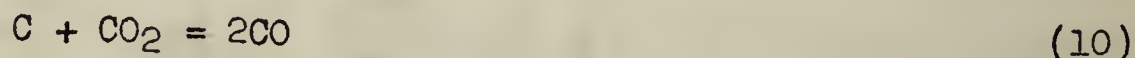
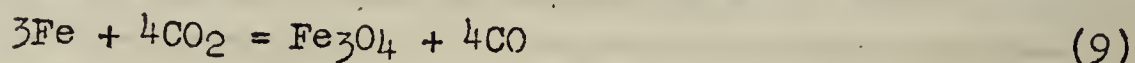
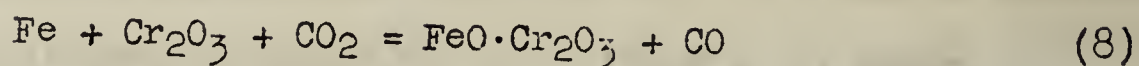
| t, °C. | $\frac{1}{K_5} = \frac{p_{H_2O}}{p_{H_2}}$ | $\frac{1}{K_6^{1/4}} = \frac{p_{H_2O}}{p_{H_2}}$ | $\frac{1}{K_7} = \frac{p_{H_2O}}{p_{CO} \cdot p_{H_2}}$ |
|-------------|--|--|---|
| 200 | - | 0.010 | 2.7×10^7 |
| 400 | - | .11 | 1.1×10^3 |
| 600 | - | .35 | 4.2 |
| 800 | - | .67 | 1.3×10^{-1} |
| 1,000 | - | .06 | 1.2×10^{-2} |
| 1,200 | 0.053 | 1.18 | 2.0×10^{-3} |
| 1,300 | .071 | 1.26 | 9.9×10^{-4} |
| 1,400 | .090 | 1.31 | 5.3×10^{-4} |

Reaction (5) has been found to be reversible in the temperature range 1,300° to 1,417° under ideal conditions and to yield reproducible equilibrium constants. Consequently, at such temperatures, the presence in the roast bed of gas with a water:hydrogen ratio of 0.07 to 0.10, or greater, constitutes a potentially oxidizing atmosphere and will tend to prevent formation of reduced iron by the reverse of reaction (5). The speed of reaction (5) decreases sharply with temperature, so that below about 1,200° it is too slow for this reaction to be an important factor in back-oxidation of roast products during cooling.

Back-oxidation to oxide without simultaneous chromite formation requires the presence of gas with a much larger water:hydrogen ratio, as shown by column 3 of table 11. If conditions are such that equilibrium is approached or reached by reaction (7), there cannot be enough water present at roasting temperatures to oxidize iron by either reaction (5) or (6). On cooling, maintenance of equilibrium in reaction (7) would preclude oxidation until about 600°, depending on relative concentrations, is reached. At lower temperatures, reaction (7) would afford no protection from oxidation by reaction (6).

- 7/ Boericke, F. S., and Bangert, W. M., Equilibria in the Reduction of Ferrous Chromite by Hydrogen and Energy Requirements in the Selective Reduction of Iron in Chromite: Bureau of Mines Report of Investigations (in course of publication).
- 8/ Kelley, K. K., Contributions to the Data on Theoretical Metallurgy. II. High-Temperature Specific-Heat Equations for Inorganic Substances: Bureau of Mines Bull. 371, 1933, 78 pp.
- 9/ Kelley, K. K., Contributions to the Data on Theoretical Metallurgy. VII. The Thermodynamic Properties of Sulfur and its Inorganic Compounds: Bureau of Mines Bull. 406, 1937, pp. 126-128.
- 10/ Kelley, K. K., Contributions to the Data on Theoretical Metallurgy. IX. The Entropies of Inorganic Substances. Revision (1940) of Data and Methods of Calculation: Bureau of Mines Bull. 434, 1941, 115 pp.
- 11/ Kelley, K. K., The Specific Heat of Pure Iron at Low Temperatures: Jour. Chem. Phys., vol. 11, 1943, pp. 16-18.

Back-oxidation reactions of carbon dioxide now will be considered:



Equilibrium constants of these three reactions are in table 12.

TABLE 12. - Equilibrium constants of reactions of carbon dioxide

| t, °C. | $\frac{1}{K_8} = \frac{p_{\text{CO}_2}}{p_{\text{CO}}}$ | $\frac{1}{K_9^{1/4}} = \frac{p_{\text{CO}_2}}{p_{\text{CO}}}$ | $\frac{1}{K_{10}} = \frac{p_{\text{CO}_2}}{p_{\text{CO}}^2}$ |
|-------------|---|---|--|
| 200 | - | 2.2 | 6.3×10^9 |
| 400 | - | 1.4 | 1.3×10^4 |
| 600 | - | .95 | 1.1×10^1 |
| 800 | - | .74 | 1.4×10^{-1} |
| 1,000 | - | .61 | 7.3×10^{-3} |
| 1,200 | 0.023 | .51 | 8.6×10^{-4} |
| 1,300 | .027 | .47 | 3.7×10^{-4} |
| 1,400 | .030 | .43 | 1.8×10^{-4} |

Reaction (8) was found to be irreversible at temperatures around 1,000°, but, by analogy with reaction (5), this may not be so in the neighborhood of the optimum roasting temperature, around 1,300°. If reaction (8) is reversible at roasting temperature, then gas with a carbon dioxide:carbon monoxide ratio of 0.03 or greater is potentially an oxidizer of the roast product. During cooling, reaction (9) would control back-oxidation, and a relatively high carbon dioxide:carbon monoxide ratio is required. If equilibrium is approached in reaction (10), too little carbon dioxide could remain at temperatures above about 700° to cause oxidation by reaction (9).

In summarizing, it may be stated that at roasting temperature around 1,300°, gas having a water-hydrogen ratio of 0.07 or a carbon dioxide:carbon monoxide ratio of 0.03 is potentially oxidizing to reduced iron in the chromite roast products. The back-oxidation reactions are slow as compared with the carbon reduction reaction, and consequently water and carbon dioxide may exhibit most of their effect in short-time roasts in preventing reduction of iron rather than in back-oxidizing it after it is formed. Approach to equilibrium in the reaction bed in the producer-gas and water-gas reactions would afford protection against back-oxidation at roasting temperatures and during cooling to 700° or 600°. Surface particles of reduced metal not protected by carbon will back-oxidize to the extent permitted by the gas composition outside the bed. These remarks are based upon the original assumption that a consideration of the back-oxidation of iron would yield about the same results as for a mixed carbide of iron and chromium or a mixed carbide of iron and chromium plus metal.

DISCUSSION

All the roasting experiments described in this report were conducted on a very small scale under as nearly ideal conditions as were obtainable with available equipment. The effect of each variable was determined in turn, holding all other variables as nearly constant as practicable. It must be emphasized, however, that no attempt was made to simulate conditions that obtain in a rotary kiln or other continuously operating commercial furnace. This is mentioned because the results tabulated in this report might give an erroneous impression if they were assumed to be quantitatively applicable to a commercial roasting unit.

On the other hand, these experiments may serve as a useful guide to larger-scale production if more consideration is given to the relative effects of changing these variables rather than to their magnitude. The results tabulated for each set of conditions may be considered as limits toward which large-scale reactions may proceed but perhaps never quite reach. These quantitative results may be approached on a larger scale if due consideration is given to the following important conditions necessary for satisfactory roasting of chromite and carbon mixtures:

1. The temperature of the roast should be as close to $1,300^{\circ}$ as is possible. Higher temperatures gain little, but lower temperatures retard the reducing reactions.
2. For rapid reduction, ore and carbon should be as fine as practicable, preferably minus 65 mesh.
3. The reduction rate is improved by intimate contact of ore and carbon. (This would indicate beneficial effects of briquetting or nodulizing the fine-ground roast mixture of carbon and chromite.)
4. Roast mixture should be protected from oxidation during the roast and while cooling.

In addition to the above general considerations, further experimenting should be done to determine which of the following procedures is best-suited to large-scale plant practice:

1. Roast the chromite with enough carbon to reduce virtually all the iron and some of the chromium (say 10 to 30 percent), and follow by an acid leach cold enough to prevent the solution of the reduced chromium while dissolving most of the reduced iron.
2. Roast the chromite with as small an excess of carbon as is feasible, thereby preventing the reduction of chromium, and follow by hot or cold acid leach to dissolve the reduced iron.

The advantages of the first procedure are that (1) the reducing roast is less sensitive to small changes in the carbon:chromite ratio and (2) the

roast product is less susceptible to back-oxidation. Reduction of large amounts of chromium (over 30 percent) should be avoided, however, because the amount of iron that can be dissolved decreases as the amount of reduced chromium increases.

The second procedure requires more careful control of roasting conditions and of carbon:chromite ratio but has a decided advantage in that more iron can be removed and, therefore, that a higher-grade product can be produced.

SUMMARY

More than 100 controlled, small-scale experiments were carried out to test certain phases of the selective reducing and leaching process for the enrichment of low-grade, domestic chromite ores. The results of these tests upon four typical chromite concentrates may be summarized as follows:

1. A roasting temperature of at least $1,200^{\circ}$ is required for the selective reduction of 60 percent or more of the iron in any reasonable time. The amount of reduced iron is larger at $1,300^{\circ}$ and $1,400^{\circ}$, and shorter roasting times are required. To produce equivalent results at $1,400^{\circ}$, $1,300^{\circ}$, and $1,200^{\circ}$ requires roasting times in the ratio of 1 to 2 to 10, respectively.
2. The use of finer sizes, below 28 mesh, of chromite is advantageous in shortening the time of roasting and decreasing the chromium losses.
3. The use of finer sizes of carbon is advantageous.
4. An amount of carbon much in excess of that necessary just to reduce the iron is to be avoided, both from the viewpoint of grade of product and loss of chromium, if hot acid is used for leaching.
5. Roasting with an amount of carbon that will reduce more than 30 percent of the chromium, in addition to the iron, is to be avoided if cold acid is to be used for leaching.
6. Chromite ores of varying composition were reduced and leached. The rate of reduction and the amount of extractable iron appear to be independent of the alumina or silica contents of the ore (within the limits of the compositions studied).
7. A higher utilization of carbon for reduction is obtained at higher temperatures.
8. Low carbon:chromite ratios give roast products that are very susceptible to back-oxidation. Higher carbon:chromite ratios give roast products more resistant to back-oxidation.

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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

NATIONAL MOTOR-GASOLINE SURVEY

WINTER 1944-45

THE WORK UPON WHICH THIS REPORT WAS BASED WAS PERFORMED UNDER A COOPERATIVE AGREEMENT BETWEEN THE BUREAU OF MINES, UNITED STATES DEPARTMENT OF THE INTERIOR, AND THE COORDINATING FUEL RESEARCH COMMITTEE



BY

O. C. BLADE

REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

NATIONAL MOTOR-GASOLINE SURVEY, WINTER 1944-45^{1/}

By O. C. Blade^{2/}

INTRODUCTION

This report on the properties of motor fuels sold through service stations in the United States is a continuation of a series of reports made in accordance with a cooperative agreement between the Coordinating Fuel Research (CFR) Committee of the Coordinating Research Council (CRC)^{3/} and the Bureau of Mines of the United States Department of the Interior. The first of these reports presented data on motor gasolines sold during the winter of 1935-36.^{4/} Further reports were issued describing motor gasolines sold during the succeeding summers and winters to and including the summer of 1941.^{5/} No reports were made on motor gasolines sold during

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- 1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3820."
- 2/ Associate petroleum chemist, Bureau of Mines.
- 3/ The Coordinating Research Council, Inc., of which the American Petroleum Institute and the Society of Automotive Engineers, Inc., are sustaining members, is devoted to direct cooperative research in developing the best combinations of equipment powered by internal-combustion engines, fuels, and lubricants.
- 4/ Lane, E. C., and Kraemer, A. J., Cooperative Fuel-Research Motor-Gasoline Survey: Bureau of Mines Rept. of Investigations 3311, Winter 1935-36, September 1936, 63 pp.
- 5/ Bureau of Mines Reports of Investigations as follows:
Lane, E. C., Cooperative Fuel-Research Motor-Gasoline Survey,
Summer 1936: R.I. 3335, January 1937, 61 pp.
Winter 1936-37: R.I. 3348, May 1937, 56 pp.
Summer 1937: R.I. 3374, December 1937, 57 pp.
Winter 1937-38: R.I. 3408, June 1938, 31 pp.
Summer 1938: R.I. 3429, December 1938, 31 pp.
Winter 1938-39: R.I. 3455, June 1939, 30 pp., 1 fig.
Summer 1939: R.I. 3492, February 1940, 30 pp., 2 figs.
Winter 1939-40: R.I. 3524, June 1940, 29 pp., 2 figs.
Summer 1940: R.I. 3550, January 1941, 29 pp., 2 figs.
Winter 1940-41: R.I. 3576, June 1941, 29 pp., 2 figs.
Summer 1941: R.I. 3611, January 1942, 31 pp., 2 figs.

the winter of 1941-42 and during the summer of 1942. However, starting with the winter of 1942-43, the semiannual reports were resumed.^{6/}

The present report presents analytical data for 1,499 samples, representing the products of approximately 105 companies. As in previous surveys, the companies covered by the survey include both large and small suppliers. Conforming to former reports, the data cover three groups of samples - regular-price, premium-price, and third-grade gasolines.

As the number of analyses submitted for samples of third-grade gasoline are not considered adequate to represent this type of motor fuel, data for these analyses have not been averaged, but the individual items are tabulated. The number of samples, items and brands comprising each group is as follows: Regular-price, 872 samples, 266 items, and 83 brands; premium-price, 584 samples, 217 items, and 72 brands; third-grade, 43 samples, 32 items, and 21 brands. The meanings of these terms as used in the surveys are as follows:

Sample: The individual supply of gasoline obtained at the filling station and analyzed in the laboratory.

Brand: The gasoline sold in a given price group under a given trade name. The figure representing the total number of brands sometimes is only approximate, because in some cases the name of the marketer is not reported.

Item: The index number assigned to a given brand in a given marketing area. The data for each item represent the average of those submitted for that brand in any one particular area. There is no relationship between the same item numbers of different areas in table 1.

The marketing districts used in the past ten reports are retained, and as far as possible the actual sampling points in each are indicated in the headings for each district in table 1.

Characteristics of regular-price, premium-price, and third-grade motor gasolines are reported, based upon data contributed through the Coordinating Fuel Research Committee for compilation by the Bureau of Mines.

^{6/} Kraemer, A. J., and Blade, O. C., Cooperative Fuel-Research Motor-Gasoline Survey,

Winter 1942-43: R.I. 3716, June 1943, 28 pp.

Kraemer, A. J., and Blade, O. C., National Motor-Gasoline Survey,

Summer 1943: R.I. 3735, December 1943, 28 pp.

Blade, O. C., National Motor-Gasoline Survey,

Winter 1943-44: R.I. 3758, May 1944, 28 pp., 1 fig.

Blade, O. C., National Motor-Gasoline Survey,

Summer 1944: R.I. 3796, January 1945, 28 pp. 2 figs.

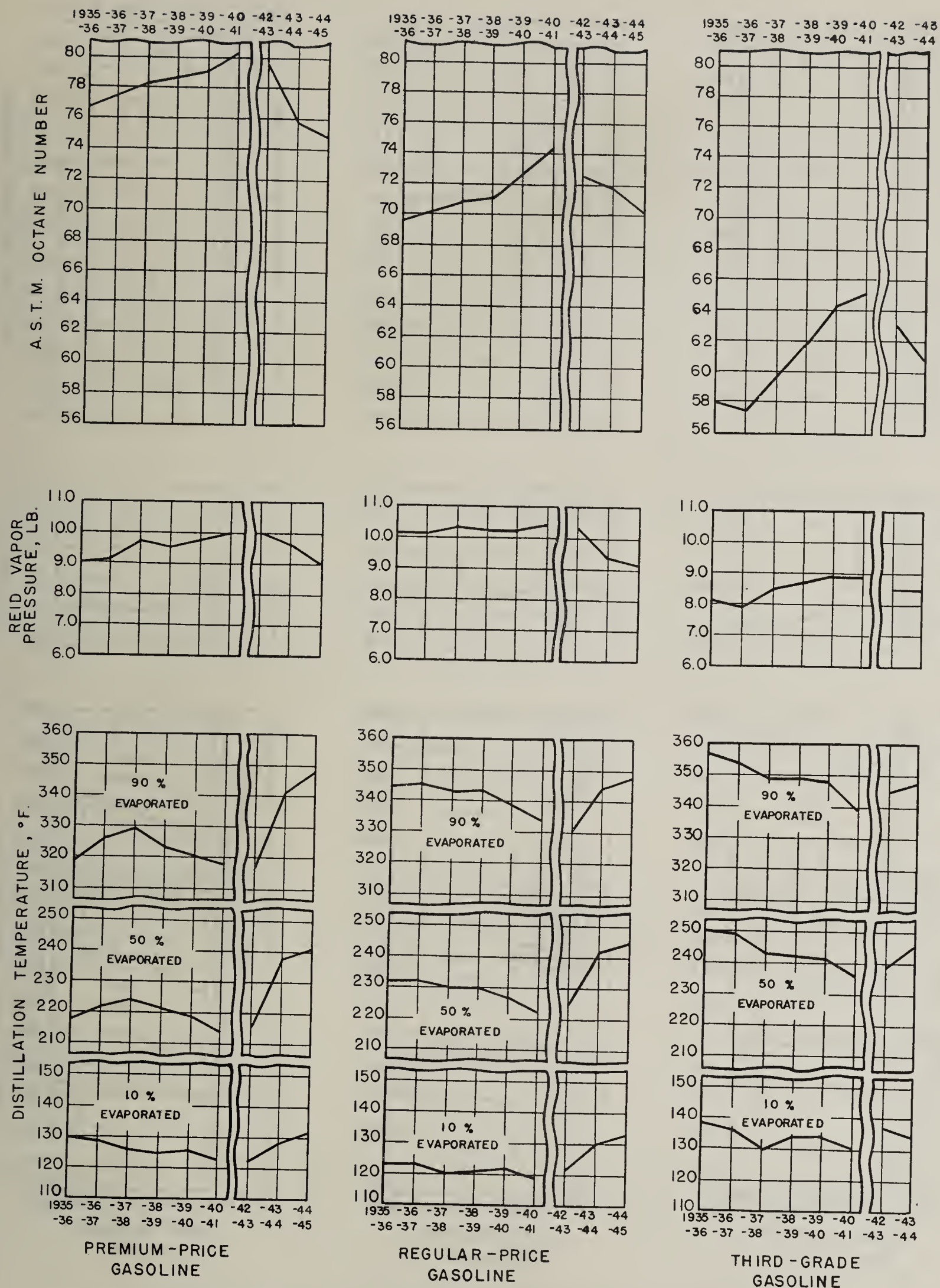


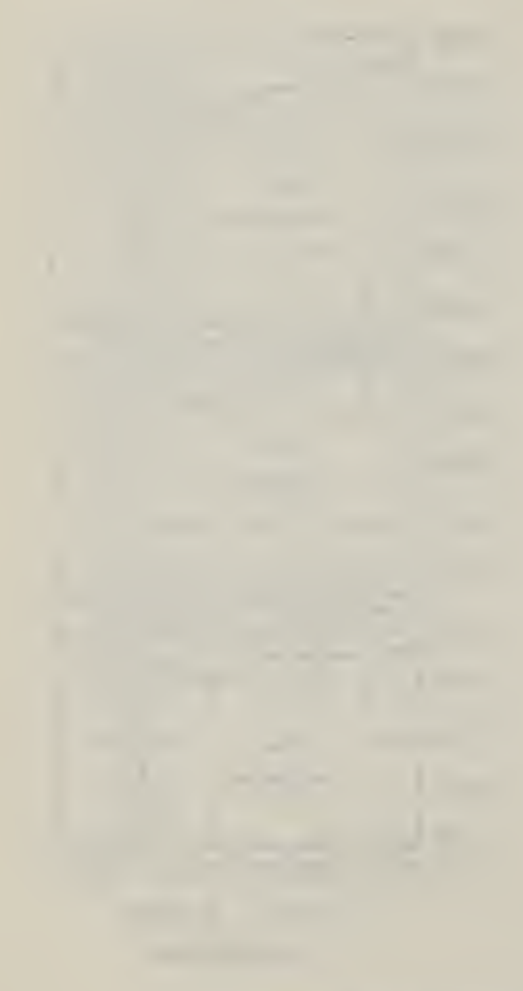
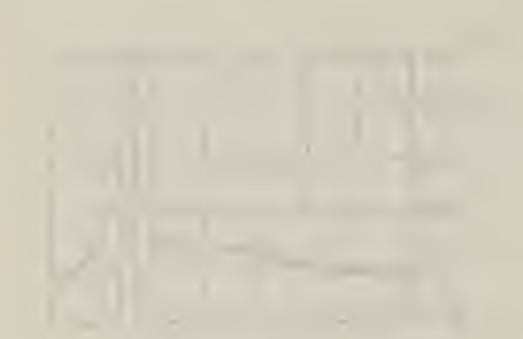
FIGURE I.- COMPARISON OF GASOLINE CHARACTERISTICS FROM WINTER SURVEYS OF 1935-36 THROUGH 1944-45.

NO PLOTS ARE SHOWN FOR THE WINTER OF 1941-42 AS THE SURVEYS WERE DISCONTINUED DURING 1942.



Figure 1: A 3x3 grid of line graphs showing various trends over time. The graphs are labeled 1 through 9. The trends include increasing, decreasing, and fluctuating lines.

1. The first part of the paper is devoted to a general discussion of the problem. It is shown that the problem is of great importance in the theory of the structure of the universe.



EXPLANATION OF TABLES AND FIGURES

Table 1 gives data for gravity, sulfur content, Reid vapor pressure, octane numbers, and distillation characteristics for motor fuels sold in 21 marketing areas in the United States during the winter of 1944-45. Octane numbers determined by the A.S.T.M. Motor Method^{7/} have been included in this report together with knock-test data by the CFR Research Method CRC Designation F-1-543.^{8/} The distillation data have been corrected to sea level and are tabulated upon the evaporated basis, as was done in the report for the winter of 1942-43 and subsequent reports, rather than upon the recovered basis, as in reports previous to that date. Averages for regular- and premium-price gasolines are given in the sections of table 1 at the bottoms of the tabulations.

The averages of table 1 have been assembled in tables 2 and 3, in which the data of the survey are summarized. Table 4 gives the minimum, maximum, and average figures for each characteristic of the regular- and premium-price gasolines. Table 5 shows similar figures for the winter survey of 1943-44.

Figure 1 is a plot of the average data for octane number, vapor pressure, and certain distillation points, taken from tables 2, 3, and 4, of the reports for the winter surveys beginning with 1935-36. Figure 2 is a similar plot of data from tables 2, 3, and 4 of the reports for the summer surveys beginning with 1936. The distillation data have been converted, where necessary, from the recovered to the evaporated basis.

^{7/} American Society for Testing Materials, 1944 Book of A.S.T.M. Standards, Part III, Nonmetallic, A.S.T.M. Designation: D 357-44, pp. 194-210, and "CRC Designation F-2-543," CFR Handbook, 1944 Edition, pp. 109-133. A description of the method according to this designation is obtainable through C. B. Veal, Manager of Coordinating Research Council, Inc., 30 Rockefeller Plaza, New York 20, N. Y.

^{8/} Obtainable in same manner as F-2-543.

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)
Boston (Mass.) area; includes cities in Massachusetts, Connecticut, Rhode Island, New Hampshire, and Maine

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number Research | A.S.T.M. | I.B.P. | Distillation range, °F. | | | | | | | | | | Percent | | Item |
|---------|----------|---------|--------------------|----------------|---------------------------|----------|--------|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------------|---------|------|
| | | | | | | | | Percent evaporated | | | | | | | | | | End point | Loss | |
| | Specific | °A.P.I. | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 1 | 0.731 | 62.0 | 0.134 | 10.7 | 74.4 | 70.2 | 88 | 102 | 122 | 148 | 174 | 225 | 275 | 337 | 362 | 400 | 1.1 | 2.5 | 1 | |
| 2 | .734 | 61.2 | .121 | 9.5 | 74.7 | 70.4 | 94 | 114 | 133 | 160 | 187 | 239 | 279 | 340 | 367 | 402 | 1.0 | 1.8 | 2 | |
| 3 | .736 | 60.8 | .100 | 9.4 | 74.2 | 70.2 | 93 | 111 | 130 | 158 | 183 | 233 | 283 | 347 | 374 | 410 | 1.0 | 2.1 | 3 | |
| 4 | .738 | 60.2 | .161 | 9.2 | 74.2 | 69.5 | 95 | 115 | 134 | 162 | 188 | 234 | 280 | 341 | 367 | 400 | 1.0 | 1.4 | 4 | |
| 5 | .740 | 59.8 | .146 | 9.0 | 73.3 | 68.4 | 89 | 111 | 131 | 161 | 187 | 235 | 284 | 349 | 376 | 413 | 1.0 | 1.9 | 5 | |
| 6 | .738 | 60.3 | .156 | 8.9 | 73.0 | 70.0 | 93 | 116 | 136 | 160 | 185 | 241 | 284 | 351 | 377 | 405 | 1.0 | 1.7 | 6 | |
| 7 | .745 | 58.5 | .090 | 9.4 | 73.3 | 70.2 | 89 | 110 | 128 | 155 | 193 | 246 | 292 | 352 | 377 | 408 | 1.1 | 2.2 | 7 | |
| 8 | .736 | 60.7 | .290 | 9.8 | 76.0 | 70.5 | 90 | 111 | 130 | 155 | 178 | 223 | 266 | 329 | 354 | 385 | 1.0 | 2.0 | 8 | |
| 9 | .738 | 60.3 | .189 | 9.2 | 74.7 | 70.5 | 93 | 119 | 136 | 164 | 193 | 243 | 287 | 349 | 375 | 406 | 1.1 | .8 | 9 | |
| 10 | .748 | 57.8 | .070 | 8.8 | 71.7 | 68.3 | 92 | 109 | 134 | 169 | 198 | 246 | 289 | 350 | 371 | 409 | 1.1 | 2.0 | 10 | |
| 11 | .725 | 63.7 | .100 | 11.6 | 73.0 | 69.0 | 85 | 96 | 116 | 142 | 174 | 234 | 283 | 358 | 386 | 416 | 1.2 | 2.8 | 11 | |
| Average | 0.737 | 60.5 | 0.142 | 9.6 | 73.9 | 69.7 | 91 | 110 | 130 | 158 | 185 | 236 | 282 | 346 | 371 | 405 | 1.1 | 1.9 | Average | |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 12 | 0.739 | 60.1 | 0.182 | 9.3 | 80.5 | 73.7 | 92 | 108 | 126 | 153 | 179 | 227 | 275 | 340 | 367 | 399 | 12 |
| 13 | .753 | 56.5 | .179 | 9.8 | 81.4 | 75.5 | 90 | 109 | 126 | 150 | 176 | 224 | 268 | 334 | 363 | 388 | 13 |
| 14 | .749 | 57.4 | .080 | 9.1 | 79.4 | 74.5 | 93 | 108 | 129 | 162 | 193 | 245 | 292 | 350 | 374 | 405 | 14 |
| 15 | .736 | 60.7 | .230 | 11.0 | 83.0 | 75.0 | 85 | 100 | 121 | 152 | 178 | 228 | 274 | 338 | 363 | 393 | 15 |
| 16 | .730 | 62.3 | .201 | 11.3 | 82.5 | 75.0 | 86 | 100 | 116 | 142 | 169 | 220 | 268 | 329 | 354 | 380 | 16 |
| 17 | .737 | 60.4 | .260 | 8.4 | 83.0 | 74.5 | 93 | 114 | 136 | 159 | 183 | 229 | 276 | 345 | 366 | 397 | 17 |
| 18 | .728 | 62.9 | .050 | 8.8 | 83.0 | 75.0 | 95 | 111 | 129 | 154 | 178 | 226 | 272 | 337 | 361 | 391 | 18 |
| 19 | .745 | 58.5 | .183 | 10.4 | 78.0 | 75.0 | 86 | 98 | 112 | 130 | 152 | 206 | 270 | 343 | 370 | 407 | 19 |
| 20 | .745 | 58.5 | .183 | 10.9 | 81.7 | 75.8 | 90 | 104 | 121 | 146 | 172 | 222 | 270 | 336 | 364 | 400 | 20 |
| 21 | .748 | 57.7 | .148 | 8.9 | 80.6 | 75.1 | 92 | 111 | 134 | 162 | 191 | 238 | 282 | 342 | 365 | 400 | 21 |
| Average | 0.741 | 59.6 | 0.168 | 9.8 | 81.1 | 74.9 | 90 | 106 | 125 | 151 | 177 | 227 | 275 | 339 | 365 | 396 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | |
|----|-------|------|------|-----|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 22 | 0.736 | 60.9 | 0.08 | 8.5 | 72.3 | 69.0 | 95 | 108 | 125 | 153 | 182 | 238 | 288 | 350 | 379 | 418 | 22 |
|----|-------|------|------|-----|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

New York area: includes cities in New York and northern New Jersey

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | Percent | | Item | | |
|---------|-------------------------|------|-------|------|------|------|----|-----|-----|-----|---------|-----------|------|-----|---------|-----|------|-----|---------|
| | Percent evaporated | | | | | | | | | | Residue | | Loss | | | | | | |
| | I.B.P. | 5 | | | | | 90 | | | | | End point | | | | | | | |
| | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | | | | | | | |
| 1 | 0.738 | 60.2 | 0.058 | 10.1 | 74.4 | 70.1 | 92 | 102 | 121 | 150 | 178 | 233 | 284 | 343 | 367 | 407 | 1.1 | 2.9 | 1 |
| 2 | .741 | 59.6 | .072 | 10.4 | 74.3 | 69.9 | 89 | 106 | 126 | 157 | 188 | 244 | 291 | 348 | 373 | 407 | 1.0 | 2.2 | 2 |
| 3 | .741 | 59.6 | .063 | 9.2 | 74.8 | 70.7 | 90 | 108 | 128 | 157 | 190 | 244 | 293 | 349 | 373 | 406 | 1.1 | 1.8 | 3 |
| 4 | .744 | 58.8 | .056 | 8.9 | 74.9 | 70.1 | 96 | 113 | 131 | 159 | 189 | 233 | 291 | 351 | 375 | 418 | .8 | 2.0 | 4 |
| 5 | .746 | 58.3 | .055 | 8.6 | 75.3 | 70.9 | 94 | 111 | 132 | 163 | 195 | 245 | 292 | 351 | 375 | 410 | .9 | 1.9 | 5 |
| 6 | .745 | 58.4 | .051 | 8.3 | 74.8 | 70.7 | 95 | 115 | 133 | 166 | 194 | 247 | 292 | 348 | 374 | 420 | 1.0 | 1.7 | 6 |
| 7 | .739 | 59.9 | .056 | 9.9 | 73.7 | 70.1 | 91 | 105 | 126 | 159 | 188 | 237 | 283 | 345 | 373 | 406 | 1.0 | 2.7 | 7 |
| 8 | .743 | 59.0 | .071 | 10.8 | 75.0 | 70.4 | 87 | 100 | 121 | 156 | 189 | 245 | 294 | 353 | 376 | 407 | 1.0 | 3.2 | 8 |
| 9 | .744 | 58.8 | .052 | 10.1 | 76.9 | 71.1 | 91 | 109 | 129 | 161 | 192 | 247 | 293 | 347 | 370 | 399 | 1.0 | 2.1 | 9 |
| 10 | .744 | 58.6 | .056 | 9.3 | 74.9 | 70.2 | 94 | 113 | 133 | 165 | 195 | 250 | 297 | 350 | 372 | 407 | 1.0 | 1.9 | 10 |
| 11 | .744 | 58.6 | .040 | 9.8 | 71.8 | 69.2 | 92 | 113 | 136 | 174 | 203 | 248 | 269 | 346 | 372 | 406 | 1.1 | 2.3 | 11 |
| 12 | .727 | 63.1 | .022 | 10.5 | 74.3 | 71.2 | 92 | 104 | 125 | 151 | 178 | 216 | 255 | 322 | 356 | 388 | .9 | 3.3 | 12 |
| 13 | .734 | 61.4 | .086 | 9.2 | 74.9 | 71.2 | 95 | 114 | 134 | 163 | 187 | 283 | 275 | 332 | 356 | 398 | .9 | 1.7 | 13 |
| 14 | .728 | 63.0 | .049 | 10.0 | 73.7 | 70.7 | 95 | 104 | 121 | 148 | 175 | 223 | 268 | 334 | 362 | 392 | .8 | 2.4 | 14 |
| Average | 0.740 | 59.8 | 0.056 | 9.7 | 74.6 | 70.5 | 92 | 108 | 128 | 159 | 189 | 243 | 286 | 344 | 370 | 405 | 1.0 | 2.3 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 15 | 0.739 | 60.1 | 0.059 | 8.6 | 78.7 | 73.5 | 99 | 120 | 134 | 156 | 180 | 229 | 343 | 368 | 401 | 1.2 | 1.0 | 15 |
| 16 | .740 | 59.8 | .057 | 9.8 | 81.0 | 76.1 | 93 | 108 | 127 | 159 | 189 | 238 | 349 | 376 | 406 | 1.1 | 2.2 | 16 |
| 17 | .744 | 58.7 | .063 | 9.4 | 80.9 | 75.6 | 90 | 108 | 131 | 164 | 194 | 244 | 352 | 376 | 422 | 1.0 | 1.8 | 17 |
| 18 | .740 | 59.7 | .054 | 9.4 | 80.0 | 74.0 | 92 | 111 | 130 | 160 | 188 | 240 | 351 | 379 | 416 | 1.0 | 1.8 | 18 |
| 19 | .746 | 58.1 | .065 | 9.1 | 81.6 | 75.7 | 92 | 112 | 131 | 163 | 194 | 249 | 349 | 371 | 408 | 1.0 | 1.6 | 19 |
| 20 | .745 | 58.5 | .049 | 8.2 | 81.5 | 75.7 | 95 | 117 | 137 | 168 | 198 | 249 | 354 | 376 | 409 | 1.0 | 1.9 | 20 |
| 21 | .744 | 58.6 | .055 | 10.2 | 80.9 | 75.6 | 92 | 108 | 128 | 162 | 196 | 252 | 354 | 379 | 408 | 1.1 | 2.3 | 21 |
| 22 | .739 | 60.0 | .071 | 10.8 | 80.9 | 75.1 | 93 | 102 | 125 | 154 | 182 | 231 | 353 | 376 | 405 | 1.1 | 3.5 | 22 |
| 23 | .750 | 57.3 | .068 | 10.3 | 81.2 | 75.0 | 91 | 107 | 127 | 162 | 196 | 251 | 353 | 376 | 403 | 1.0 | 2.3 | 23 |
| 24 | .747 | 57.9 | .063 | 10.1 | 83.5 | 75.8 | 89 | 102 | 122 | 152 | 181 | 238 | 351 | 373 | 402 | 1.0 | 2.8 | 24 |
| 25 | .731 | 62.1 | .034 | 11.0 | 81.4 | 75.7 | 90 | 107 | 128 | 156 | 182 | 224 | 331 | 362 | 396 | 1.2 | 2.3 | 25 |
| 26 | .738 | 60.3 | .180 | 7.8 | 74.0 | 70.5 | 100 | 129 | 149 | 175 | 196 | 232 | 318 | 346 | 378 | 1.1 | .9 | 26 |
| 27 | .726 | 63.5 | - | - | 80.4 | 76.0 | - | - | - | - | - | - | - | - | - | - | - | 27 |
| 28 | .747 | 58.0 | .028 | 7.4 | 76.0 | 74.6 | 102 | 132 | 153 | 187 | 216 | 263 | 357 | 381 | 408 | .9 | 1.7 | 28 |
| Average | 0.741 | 59.5 | 0.066 | 9.4 | 80.1 | 74.9 | 94 | 113 | 132 | 163 | 192 | 242 | 347 | 372 | 405 | 1.1 | 2.0 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | | |
|----|-------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 29 | 0.735 | 61.0 | 0.11 | 9.0 | 74.0 | 69.5 | 90 | 118 | 126 | 152 | 176 | 227 | 345 | 375 | 410 | 1.2 | 1.8 | 29 |
| 30 | .733 | 61.6 | .05 | 10.0 | 72.5 | 69.5 | 96 | 111 | 128 | 156 | 182 | 227 | 328 | 359 | 402 | 1.2 | 2.8 | 30 |
| 31 | .714 | 66.7 | .04 | 5.0 | 64.5 | 62.0 | 106 | 155 | 181 | 211 | 227 | 249 | 309 | 334 | 388 | 1.3 | .7 | 31 |

TABLE 1.-Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Washington (D.C.) area: includes Atlantic City, N. J., and cities in Maryland, Virginia, and West Virginia

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Distillation range, of. | | | | | | | | Per cent | | Item | |
|---------|----------|---------|--------------------|----------------|---------------|----------|--------|-------------------------|-----|-----|-----|-----|-----|-----|-----|--------------|---------|------|---------|
| | Specific | °A.P.I. | | | Research | A.S.T.M. | | Percent evaporated | | | | | | | | End point | Residue | | Loss |
| | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | |
| 1 | 0.742 | 59.1 | 0.061 | 10.3 | 74.2 | 69.7 | 87 | 102 | 124 | 158 | 191 | 252 | 298 | 352 | 375 | 405 | 1.3 | 2.2 | 1 |
| 2 | .741 | 59.4 | .030 | 11.6 | 72.2 | 68.9 | 81 | 93 | 116 | 156 | 199 | 252 | 298 | 353 | 372 | 396 | 1.1 | 3.4 | 2 |
| 3 | .744 | 58.8 | .088 | 11.1 | 73.2 | 69.2 | 91 | 104 | 123 | 159 | 196 | 248 | 288 | 347 | 373 | 408 | 1.1 | 2.9 | 3 |
| 4 | .745 | 58.5 | .120 | 9.6 | 73.0 | 69.5 | 94 | 111 | 132 | 167 | 199 | 254 | 299 | 356 | 382 | 429 | .9 | 1.6 | 4 |
| 5 | .726 | 63.3 | .042 | 10.3 | 74.8 | 71.5 | 89 | 105 | 122 | 148 | 175 | 223 | 263 | 321 | 346 | 379 | 1.2 | 1.8 | 5 |
| 6 | .744 | 58.8 | .063 | 10.7 | 73.9 | 69.8 | 85 | 99 | 122 | 159 | 197 | 254 | 297 | 352 | 374 | 406 | 1.1 | 2.8 | 6 |
| 7 | .745 | 58.4 | .035 | 10.9 | 76.0 | 71.1 | 87 | 98 | 118 | 154 | 192 | 253 | 299 | 350 | 371 | 397 | 1.1 | 2.9 | 7 |
| 8 | .742 | 59.2 | .080 | 11.2 | 74.5 | 70.5 | 87 | 100 | 121 | 160 | 197 | 250 | 293 | 347 | 367 | 395 | 1.1 | 3.7 | 8 |
| 9 | .735 | 61.1 | .140 | 10.1 | 74.8 | 70.0 | 92 | 107 | 123 | 155 | 185 | 243 | 293 | 352 | 379 | 421 | 1.2 | 2.1 | 9 |
| 10 | .736 | 60.8 | .029 | 11.2 | 73.9 | 70.0 | 84 | 98 | 115 | 144 | 176 | 237 | 288 | 344 | 364 | 406 | 1.0 | 2.6 | 10 |
| 11 | .721 | 64.7 | .040 | 9.8 | 71.5 | 70.0 | 96 | 108 | 125 | 153 | 181 | 222 | 256 | 304 | 326 | 357 | .8 | 2.2 | 11 |
| Average | 0.738 | 60.2 | 0.066 | 10.6 | 73.8 | 70.0 | 88 | 102 | 122 | 156 | 190 | 244 | 288 | 343 | 366 | 400 | 1.1 | 2.6 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 12 | 0.754 | 56.3 | 0.063 | 7.9 | 82.4 | 76.0 | 98 | 114 | 130 | 162 | 198 | 253 | 301 | 356 | 380 | 404 | 1.0 | 1.9 | 12 |
| 13 | .752 | 56.8 | .089 | 9.3 | 83.4 | 75.6 | 96 | 117 | 135 | 167 | 199 | 255 | 303 | 359 | 384 | 408 | .9 | 1.6 | 13 |
| 14 | .758 | 55.2 | - | - | 80.0 | 75.8 | - | - | - | - | - | - | - | - | - | - | - | - | 14 |
| 15 | .742 | 59.1 | .079 | 9.0 | 82.6 | 74.9 | 94 | 115 | 133 | 163 | 195 | 249 | 296 | 353 | 377 | 407 | 1.1 | 1.4 | 15 |
| 16 | .752 | 56.8 | .090 | 7.8 | 82.4 | 76.3 | 96 | 112 | 133 | 166 | 199 | 256 | 303 | 357 | 378 | 408 | .8 | 2.3 | 16 |
| 17 | .739 | 60.0 | .063 | 8.6 | 82.5 | 75.6 | 92 | 108 | 127 | 156 | 185 | 239 | 288 | 349 | 372 | 401 | 1.0 | 2.1 | 17 |
| 18 | .720 | 65.1 | - | 11.1 | - | 75.1 | 85 | 100 | 113 | 132 | 152 | 200 | 260 | 347 | 377 | 399 | 1.0 | 2.0 | 18 |
| 19 | .730 | 62.4 | - | - | - | 76.1 | - | - | - | - | - | - | - | - | - | - | - | - | 19 |
| 20 | .731 | 62.1 | - | - | - | 76.0 | - | - | - | - | - | - | - | - | - | - | - | - | 20 |
| Average | 0.742 | 59.3 | 0.077 | 9.0 | 82.2 | 75.7 | 94 | 111 | 129 | 158 | 188 | 242 | 292 | 354 | 378 | 405 | 1.0 | 1.9 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | | | |
|----|-------|------|------|------|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 21 | 0.743 | 58.9 | 0.12 | 9.2 | 73.0 | 69.5 | 89 | 109 | 138 | 176 | 198 | 245 | 285 | 337 | 360 | 406 | 1.0 | 3.0 | 21 |
| 22 | .741 | 59.6 | .03 | 11.8 | 74.0 | 69.5 | 83 | 87 | 107 | 143 | 182 | 245 | 293 | 348 | 368 | 395 | 1.0 | 4.0 | 22 |
| 23 | .744 | 58.6 | .10 | 9.2 | 74.0 | 69.0 | 93 | 109 | 128 | 158 | 189 | 247 | 297 | 358 | 377 | 404 | 1.0 | 2.0 | 23 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Pittsburgh () area: includes other cities in Pennsylvania

Regular-price gasoline

| Item | Gravity Specific | Sulfur, percent | R.V.P., lb. | Octane number Research | A.S.T.M. | Distillation range, °F. | | | | | | | | | | Percent | | End point | Item |
|---------|---------------------|--------------------|----------------|---------------------------|----------|-------------------------|--------------------|-----|-----|-----|-----|-----|-----|-----|-----|---------|------|--------------|------|
| | | | | | | Percent evaporated | | | | | | | | | | Residue | Loss | | |
| | | | | | | I.B.P. | Percent evaporated | | | | | | | | | | | | |
| | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | | |
| 1 | 0.736 | 0.095 | 10.8 | 77.9 | 71.1 | 93 | 103 | 125 | 156 | 189 | 245 | 282 | 338 | 362 | 397 | 1 | | | |
| 2 | .741 | .110 | 10.0 | 74.7 | 69.8 | 91 | 109 | 130 | 162 | 194 | 246 | 289 | 348 | 374 | 413 | 2 | | | |
| 3 | .739 | .101 | 10.8 | 73.5 | 69.7 | 89 | 103 | 128 | 163 | 195 | 244 | 287 | 347 | 372 | 407 | 3 | | | |
| 4 | .731 | .121 | 11.6 | 77.0 | 70.1 | 90 | 103 | 119 | 144 | 172 | 234 | 283 | 341 | 367 | 398 | 4 | | | |
| 5 | .740 | .095 | 10.1 | 74.7 | 70.1 | 91 | 111 | 127 | 162 | 195 | 249 | 292 | 346 | 371 | 405 | 5 | | | |
| 6 | .734 | .084 | 10.4 | 74.4 | 70.5 | 89 | 108 | 129 | 163 | 194 | 244 | 288 | 340 | 365 | 399 | 6 | | | |
| 7 | .744 | .045 | 10.5 | 77.1 | 71.8 | 90 | 106 | 126 | 160 | 195 | 254 | 296 | 346 | 367 | 402 | 7 | | | |
| 8 | .737 | .111 | 11.0 | 75.3 | 70.0 | 89 | 105 | 128 | 161 | 194 | 248 | 289 | 345 | 371 | 399 | 8 | | | |
| 9 | .732 | .117 | 10.3 | 75.6 | 69.8 | 89 | 104 | 119 | 143 | 171 | 237 | 289 | 342 | 363 | 394 | 9 | | | |
| 10 | .732 | .088 | 10.8 | 75.6 | 70.4 | 93 | 104 | 122 | 152 | 182 | 239 | 281 | 336 | 359 | 387 | 10 | | | |
| 11 | .752 | .060 | 10.4 | 78.5 | 71.5 | 92 | 111 | 131 | 162 | 197 | 263 | 301 | 339 | 358 | 393 | 11 | | | |
| 12 | .732 | .150 | 10.8 | 75.8 | 69.8 | 88 | 96 | 116 | 141 | 170 | 231 | 285 | 340 | 368 | 412 | 12 | | | |
| 13 | .714 | .054 | 11.3 | 72.7 | 70.5 | 90 | 103 | 121 | 150 | 176 | 220 | 258 | 316 | 344 | 389 | 13 | | | |
| 14 | .728 | .044 | 10.2 | 74.3 | 70.9 | 93 | 106 | 127 | 158 | 189 | 238 | 281 | 335 | 354 | 380 | 14 | | | |
| 15 | .729 | .040 | 11.2 | 73.4 | 70.6 | 91 | 102 | 123 | 156 | 186 | 241 | 292 | 351 | 370 | 394 | 15 | | | |
| 16 | .731 | .052 | 9.5 | 76.3 | 72.1 | 92 | 110 | 129 | 159 | 188 | 242 | 294 | 358 | 386 | 416 | 16 | | | |
| 17 | .730 | .044 | 9.4 | 72.5 | 70.2 | 95 | 113 | 134 | 165 | 194 | 240 | 284 | 339 | 359 | 389 | 17 | | | |
| 18 | .717 | .059 | 8.6 | 73.1 | 71.6 | 98 | 124 | 145 | 175 | 198 | 233 | 260 | 299 | 318 | 345 | 18 | | | |
| Average | 0.733 | 0.082 | 10.4 | 75.1 | 70.6 | 91 | 107 | 127 | 157 | 188 | 242 | 285 | 339 | 363 | 396 | Average | | | |

Premium-price gasoline

| | | | | | | | | | | | | | | | |
|---------|-------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 19 | 0.748 | 0.105 | 9.0 | 81.9 | 74.6 | 94 | 133 | 161 | 196 | 248 | 294 | 350 | 376 | 408 | 19 |
| 20 | .740 | .097 | 9.8 | 80.0 | 74.6 | 94 | 132 | 162 | 194 | 243 | 289 | 348 | 376 | 408 | 20 |
| 21 | .741 | .108 | 9.6 | 81.2 | 75.1 | 114 | 136 | 169 | 199 | 244 | 286 | 346 | 373 | 405 | 21 |
| 22 | .731 | .150 | 11.0 | 76.0 | 69.0 | 88 | 118 | 143 | 170 | 228 | 280 | 333 | 359 | 390 | 22 |
| 23 | .741 | .130 | 11.0 | 76.0 | 70.0 | 91 | 118 | 148 | 180 | 237 | 280 | 337 | 362 | 404 | 23 |
| 24 | .735 | .100 | 10.4 | 80.4 | 74.8 | 101 | 123 | 153 | 183 | 238 | 286 | 345 | 370 | 402 | 24 |
| 25 | .742 | .135 | 9.0 | 82.3 | 75.8 | 108 | 125 | 156 | 187 | 243 | 286 | 346 | 375 | 408 | 25 |
| 26 | .742 | .131 | 9.6 | 81.4 | 75.4 | 121 | 138 | 169 | 197 | 247 | 290 | 350 | 375 | 408 | 26 |
| 27 | .742 | .038 | 8.5 | 78.2 | 75.0 | 111 | 132 | 166 | 200 | 251 | 303 | 367 | 390 | 416 | 27 |
| 28 | .746 | .089 | 11.7 | 82.6 | 76.1 | 90 | 111 | 130 | 163 | 217 | 272 | 339 | 366 | 412 | 28 |
| 29 | .722 | .054 | 11.1 | 80.9 | 76.1 | 92 | 124 | 150 | 174 | 221 | 272 | 339 | 364 | 412 | 29 |
| 30 | .731 | .041 | 10.2 | 81.9 | 75.9 | 93 | 130 | 162 | 191 | 238 | 280 | 334 | 354 | 392 | 30 |
| 31 | .724 | .040 | 11.1 | 80.4 | 75.4 | 88 | 118 | 148 | 177 | 228 | 274 | 334 | 357 | 386 | 31 |
| 32 | .742 | .041 | 6.4 | 82.2 | 76.3 | 106 | 151 | 180 | 205 | 249 | 291 | 349 | 369 | 396 | 32 |
| 33 | .732 | .044 | 7.8 | 76.4 | 74.6 | 97 | 139 | 170 | 193 | 240 | 281 | 338 | 368 | 405 | 33 |
| Average | 0.737 | 0.087 | 9.7 | 80.1 | 74.6 | 94 | 129 | 158 | 187 | 240 | 287 | 345 | 370 | 401 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | |
|----|-------|------|------|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 34 | 0.735 | 0.10 | 10.5 | 74.5 | 69.8 | 85 | 123 | 154 | 186 | 242 | 289 | 349 | 379 | 406 | 34 |
| 35 | .733 | .12 | 12.0 | 78.0 | 70.5 | 85 | 112 | 143 | 173 | 242 | 284 | 338 | 362 | 392 | 35 |
| 36 | .741 | .15 | 11.2 | 75.0 | 68.5 | 89 | 133 | 173 | 207 | 254 | 286 | 342 | 377 | 415 | 36 |
| 37 | .745 | .12 | 9.6 | 74.5 | 69.5 | 88 | 121 | 160 | 194 | 242 | 283 | 336 | 364 | 410 | 37 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Cleveland (Ohio) area; includes other cities in Ohio

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | Percent | | Item |
|---------|-------------------------|--------------------|-----------------|-------------|---------------|----------|--------|--------------------|-----|-----|-----|-----------|-----------|---------|---------|-----|------|
| | Percent evaporated | | | | | | | | | | | End point | Residue | Loss | | | |
| | I.B.P. | Percent evaporated | | | | | 90 | 95 | | | | | | | | | |
| | | 5 | 10 | 20 | 30 | 50 | | | 70 | | | | | | | | |
| | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Percent evaporated | | | | | End point | Residue | Loss | | |
| | Specific | A.P.I. | | | Research | A.S.T.M. | | 5 | 10 | 20 | 30 | 50 | | | | 70 | 90 |
| 1 | 0.738 | 60.2 | 0.068 | 10.9 | 75.8 | 70.2 | 87 | 105 | 120 | 148 | 179 | 237 | 286 | 357 | 382 | 1.1 | 2.7 |
| 2 | .732 | 61.8 | .043 | 9.9 | 74.4 | 70.8 | 95 | 114 | 130 | 158 | 185 | 233 | 283 | 355 | 384 | 1.1 | 1.8 |
| 3 | .742 | 59.3 | .078 | 9.2 | 74.4 | 70.0 | 93 | 111 | 128 | 156 | 187 | 243 | 290 | 349 | 371 | 1.1 | 1.9 |
| 4 | .734 | 61.3 | .043 | 9.5 | 72.2 | 70.0 | 93 | 116 | 133 | 167 | 194 | 243 | 291 | 352 | 376 | 1.0 | 2.0 |
| 5 | .728 | 62.8 | .048 | 9.0 | 72.8 | 70.0 | 98 | 120 | 136 | 162 | 186 | 230 | 274 | 335 | 365 | 1.2 | 1.3 |
| 6 | .730 | 62.4 | .050 | 9.7 | 73.6 | 70.4 | 92 | 112 | 131 | 160 | 185 | 234 | 282 | 345 | 369 | 1.1 | 1.7 |
| 7 | .734 | 61.3 | .068 | 9.0 | - | 71.5 | 98 | 116 | 129 | 149 | 179 | 234 | 293 | 371 | 415 | 1.0 | 1.0 |
| 8 | .739 | 60.0 | .080 | 9.8 | 75.3 | 70.3 | 97 | 114 | 131 | 160 | 191 | 244 | 290 | 350 | 377 | 1.0 | 2.1 |
| 9 | .745 | 58.4 | .067 | 9.1 | 75.2 | 70.3 | 93 | 112 | 131 | 162 | 195 | 247 | 293 | 346 | 373 | 1.1 | 1.7 |
| 10 | .742 | 59.1 | .120 | 8.9 | 74.9 | 70.4 | 92 | 109 | 131 | 166 | 201 | 255 | 300 | 355 | 385 | 1.1 | 1.5 |
| 11 | .734 | 61.3 | .022 | 9.8 | 73.6 | 70.0 | 91 | 105 | 121 | 148 | 173 | 225 | 281 | 357 | 387 | 1.0 | 2.0 |
| 12 | .739 | 60.1 | .075 | 9.3 | 75.8 | 71.0 | 89 | 107 | 123 | 155 | 184 | 241 | 297 | 352 | 380 | 1.0 | 1.0 |
| 13 | .727 | 63.2 | .110 | 12.6 | - | 66.5 | 89 | 92 | 109 | 132 | 154 | 220 | 278 | 344 | 368 | 1.2 | 3.8 |
| 14 | .736 | 60.9 | .070 | 10.2 | 76.0 | 69.5 | 84 | 103 | 123 | 151 | 174 | 228 | 284 | 356 | 382 | 2.1 | .9 |
| 15 | .740 | 59.8 | - | - | - | 69.9 | - | - | - | - | - | - | - | - | - | - | - |
| Average | 0.736 | 60.8 | 0.067 | 9.8 | 74.5 | 70.1 | 92 | 110 | 127 | 155 | 183 | 237 | 287 | 352 | 380 | 1.2 | 1.8 |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 16 | 0.739 | 60.1 | 0.064 | 10.2 | 81.6 | 75.5 | 90 | 104 | 125 | 153 | 182 | 237 | 290 | 360 | 387 | 1.2 | 2.2 |
| 17 | .735 | 61.1 | .066 | 9.4 | 79.1 | 74.7 | 92 | 111 | 130 | 159 | 188 | 237 | 284 | 350 | 375 | 1.0 | 1.9 |
| 18 | .736 | 60.7 | .058 | 8.4 | 79.3 | 75.2 | 99 | 120 | 136 | 161 | 186 | 237 | 284 | 341 | 363 | 1.0 | 1.3 |
| 19 | .735 | 61.0 | .053 | 10.4 | 79.3 | 75.0 | 91 | 110 | 127 | 159 | 188 | 242 | 298 | 358 | 382 | 1.1 | 2.1 |
| 20 | .729 | 62.5 | .070 | 10.0 | 79.3 | 75.0 | 90 | 112 | 129 | 154 | 179 | 226 | 273 | 336 | 364 | .9 | 1.5 |
| 21 | .729 | 62.5 | .041 | 9.3 | 82.5 | 76.0 | 94 | 117 | 121 | 145 | 175 | 221 | 271 | 352 | 385 | 1.0 | 5.5 |
| 22 | .737 | 60.4 | .067 | 7.7 | - | 75.7 | 117 | 146 | 159 | 180 | 203 | 253 | 294 | 363 | 388 | 1.0 | 1.0 |
| 23 | .738 | 60.3 | .041 | 10.1 | 79.5 | 76.5 | 103 | 118 | 142 | 170 | 201 | 253 | 299 | 364 | 389 | 1.0 | 1.8 |
| 24 | .739 | 60.0 | .034 | 8.6 | 83.0 | 76.3 | 98 | 119 | 139 | 165 | 190 | 240 | 290 | 354 | 378 | 1.0 | 1.0 |
| 25 | .743 | 58.9 | .076 | 8.1 | 82.6 | 75.6 | 112 | 129 | 150 | 180 | 206 | 253 | 305 | 362 | 392 | 1.0 | 1.5 |
| 26 | .728 | 62.8 | .031 | 8.7 | 78.3 | 74.5 | 95 | 108 | 125 | 152 | 177 | 223 | 270 | 336 | 361 | .9 | 1.3 |
| 27 | .738 | 60.3 | .036 | 11.8 | 83.7 | 76.3 | 87 | 104 | 114 | 137 | 155 | 201 | 260 | 336 | 366 | 1.0 | - |
| 28 | .724 | 63.9 | - | - | - | 74.8 | - | - | - | - | - | - | - | - | - | - | - |
| 29 | .735 | 61.1 | - | - | - | 75.8 | - | - | - | - | - | - | - | - | - | - | - |
| 30 | .733 | 61.6 | - | - | - | 76.1 | - | - | - | - | - | - | - | - | - | - | - |
| 31 | .740 | 59.7 | - | - | - | 75.3 | - | - | - | - | - | - | - | - | - | - | - |
| 32 | .731 | 62.1 | - | - | - | 74.8 | - | - | - | - | - | - | - | - | - | - | - |
| Average | 0.735 | 61.1 | 0.053 | 9.4 | 80.8 | 75.5 | 97 | 117 | 133 | 160 | 186 | 235 | 285 | 351 | 378 | 1.0 | 1.9 |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | |
|----|-------|------|------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 33 | 0.703 | 69.8 | 0.03 | 7.2 | 63.5 | 62.0 | 114 | 132 | 143 | 155 | 164 | 182 | 201 | 223 | 234 | 0.4 | 1.6 |
| 34 | .724 | 63.9 | .11 | 7.6 | 33.0 | 32.0 | 96 | 125 | 149 | 182 | 205 | 242 | 281 | 329 | 350 | 1.2 | 1.8 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Detroit (Mich.) area: includes other cities in Michigan

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Distillation range, °F. | | | | | | | Percent | | Item | |
|---------|----------|---------|--------------------|----------------|---------------|----------|--------|-------------------------|-----|-----|-----|-----|--------------|---------|---------|-----|------|---------|
| | Specific | °A.P.I. | | | Research | A.S.T.M. | | Percent evaporated | | | | | End point | Residue | Loss | | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | | | | 70 | | 90 |
| 1 | 0.730 | 62.3 | 0.067 | 9.7 | 72.0 | 69.6 | 90 | 108 | 128 | 158 | 186 | 236 | 282 | 348 | 376 | 1.1 | 2.0 | 1 |
| 2 | .732 | 61.7 | .062 | 9.3 | 73.6 | 70.3 | 88 | 104 | 120 | 145 | 175 | 240 | 294 | 350 | 372 | 1.1 | 1.9 | 2 |
| 3 | .727 | 63.1 | .058 | 10.5 | 73.3 | 70.2 | 87 | 103 | 121 | 150 | 176 | 224 | 271 | 337 | 364 | 1.2 | 2.8 | 3 |
| 4 | .730 | 62.3 | .070 | 10.6 | 73.0 | 69.0 | 90 | 107 | 126 | 155 | 182 | 232 | 276 | 346 | 377 | 1.3 | 2.7 | 4 |
| 5 | .730 | 62.4 | .122 | 11.8 | 74.0 | 70.6 | 84 | 98 | 117 | 147 | 179 | 234 | 276 | 337 | 370 | 1.1 | 2.6 | 5 |
| 6 | .715 | 66.3 | .085 | 10.6 | 71.8 | 69.8 | 85 | 104 | 119 | 144 | 167 | 210 | 251 | 321 | 362 | 1.2 | 1.6 | 6 |
| 7 | .726 | 63.5 | .104 | 10.5 | 72.4 | 69.4 | 90 | 104 | 123 | 151 | 178 | 227 | 268 | 338 | 371 | 1.1 | 1.9 | 7 |
| 8 | .732 | 61.7 | .063 | 9.7 | 72.2 | 69.9 | 93 | 111 | 131 | 161 | 187 | 236 | 282 | 342 | 367 | 1.1 | 2.3 | 8 |
| 9 | .729 | 62.6 | .079 | 10.4 | 72.2 | 70.1 | 84 | 104 | 124 | 154 | 179 | 224 | 259 | 318 | 346 | 1.1 | 2.6 | 9 |
| 10 | .723 | 64.2 | .120 | 11.8 | 74.0 | 70.0 | 84 | 96 | 111 | 134 | 158 | 220 | 278 | 343 | 367 | .8 | 2.2 | 10 |
| 11 | .730 | 62.4 | .088 | 9.3 | 73.0 | 70.0 | 98 | 115 | 133 | 162 | 183 | 235 | 278 | 341 | 368 | 1.2 | 1.9 | 11 |
| Average | 0.728 | 63.0 | 0.083 | 10.4 | 72.9 | 69.9 | 88 | 105 | 123 | 151 | 177 | 229 | 274 | 338 | 367 | 1.1 | 2.2 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 12 | 0.712 | 67.2 | 0.038 | 12.5 | 78.8 | 76.0 | 80 | 91 | 101 | 123 | 146 | 201 | 257 | 338 | 371 | 1.2 | 1.8 | 12 |
| 13 | .730 | 62.4 | .076 | 10.1 | 80.8 | 75.8 | 88 | 102 | 117 | 140 | 164 | 224 | 283 | 353 | 381 | 1.1 | 1.9 | 13 |
| 14 | .728 | 63.0 | .063 | 10.2 | 79.5 | 75.2 | 87 | 107 | 123 | 151 | 179 | 224 | 273 | 335 | 363 | 1.1 | 2.4 | 14 |
| 15 | .733 | 61.6 | .050 | 10.6 | 76.0 | 74.0 | 93 | 107 | 131 | 162 | 189 | 236 | 280 | 347 | 373 | 1.2 | 2.8 | 15 |
| 16 | .734 | 61.3 | .132 | 10.7 | 79.5 | 74.8 | 87 | 102 | 120 | 149 | 181 | 238 | 284 | 343 | 369 | 1.1 | 2.4 | 16 |
| 17 | .719 | 65.3 | .068 | 11.5 | 75.2 | 73.1 | 87 | 103 | 119 | 144 | 163 | 211 | 261 | 334 | 368 | 1.2 | 2.8 | 17 |
| 18 | .740 | 59.8 | .166 | 9.3 | 82.5 | 75.5 | 93 | 110 | 127 | 157 | 188 | 244 | 289 | 347 | 368 | 1.1 | 1.9 | 18 |
| 19 | .726 | 63.4 | .054 | 10.6 | 79.3 | 75.4 | 86 | 106 | 125 | 152 | 176 | 221 | 265 | 334 | 367 | 1.2 | 2.5 | 19 |
| 20 | .725 | 63.8 | .053 | 10.6 | 78.2 | 74.6 | 87 | 105 | 128 | 158 | 183 | 221 | 255 | 316 | 355 | 1.0 | 2.9 | 20 |
| 21 | .717 | 66.0 | .090 | 12.6 | 78.5 | 74.5 | 84 | 90 | 107 | 128 | 149 | 204 | 264 | 346 | 381 | 1.0 | 4.0 | 21 |
| 22 | .730 | 62.3 | .070 | 10.4 | 79.5 | 74.5 | 94 | 101 | 113 | 134 | 155 | 206 | 261 | 327 | 351 | 1.1 | 2.9 | 22 |
| 23 | .731 | 62.1 | .041 | 10.1 | 76.4 | 73.8 | 89 | 110 | 128 | 159 | 188 | 235 | 285 | 352 | 377 | 1.2 | 1.8 | 23 |
| 24 | .731 | 62.2 | - | 11.1 | - | 74.6 | 79 | 96 | 113 | 136 | 163 | 224 | 280 | 343 | 365 | .9 | 2.0 | 24 |
| 25 | .741 | 59.6 | - | 9.7 | - | 75.1 | 82 | 106 | 122 | 148 | 177 | 242 | 296 | 350 | 369 | .9 | 1.1 | 25 |
| Average | 0.728 | 62.9 | 0.075 | 10.7 | 78.7 | 74.8 | 87 | 103 | 120 | 146 | 172 | 224 | 274 | 340 | 368 | 1.1 | 2.4 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | | |
|----|-------|------|-------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 26 | 0.732 | 61.7 | 0.120 | 8.4 | 74.5 | 70.5 | 110 | 119 | 136 | 163 | 187 | 232 | 271 | 329 | 354 | 1.0 | 2.0 | 26 |
|----|-------|------|-------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)
Atlanta (Ga.) area: includes cities in Georgia, Florida, and South Carolina

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | | | | Item | | | | |
|---------|-------------------------|------|--------------------|----------------|---------------|------|--------|--------------------|----------|----------|-----|-----|-----|-----|--------------|---------|-----|------|---------|----|---------|------|
| | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Percent evaporated | | | | | | | End point | Percent | | | | | | |
| | | | | | | | | A.P.I. | Research | A.S.T.M. | 5 | 10 | 20 | 30 | | 50 | 70 | | 90 | 95 | Residue | Loss |
| | | | | | | | | | | | | | | | | | | | | | | |
| 1 | - | - | - | 8.6 | - | - | 90 | 112 | 139 | 168 | 197 | 246 | 294 | 349 | 372 | 404 | 1.0 | 1.5 | 1 | | | |
| 2 | 0.746 | 58.2 | 0.062 | 7.8 | 74.4 | 70.1 | 96 | 116 | 135 | 165 | 196 | 246 | 292 | 352 | 376 | 409 | .9 | 1.5 | 2 | | | |
| 3 | .748 | 57.6 | .079 | 8.1 | 75.8 | 70.3 | 102 | 121 | 143 | 173 | 203 | 251 | 294 | 353 | 376 | 410 | 1.1 | 1.9 | 3 | | | |
| 4 | .749 | 57.5 | .059 | 8.3 | 76.0 | 69.0 | 103 | 123 | 143 | 174 | 205 | 252 | 298 | 353 | 379 | 410 | 1.1 | 1.7 | 4 | | | |
| 5 | .743 | 58.9 | .054 | 8.9 | 74.0 | 70.0 | 91 | 116 | 137 | 167 | 194 | 243 | 290 | 350 | 375 | 410 | 1.2 | 1.3 | 5 | | | |
| 6 | .750 | 57.1 | .060 | 7.6 | 74.8 | 70.0 | 97 | 120 | 145 | 174 | 204 | 254 | 300 | 354 | 377 | 401 | 1.0 | 1.5 | 6 | | | |
| 7 | .753 | 56.5 | .055 | 8.4 | 75.5 | 69.8 | 94 | 105 | 127 | 158 | 201 | 258 | 300 | 355 | 375 | 408 | .9 | 3.1 | 7 | | | |
| 8 | .744 | 58.6 | .080 | 8.8 | 75.5 | 69.5 | 96 | 106 | 129 | 160 | 190 | 240 | 288 | 349 | 373 | 406 | .8 | 4.2 | 8 | | | |
| 9 | .749 | 57.5 | .064 | 7.1 | 73.8 | 70.0 | 104 | 123 | 143 | 173 | 201 | 249 | 295 | 350 | 372 | 402 | .9 | 2.4 | 9 | | | |
| 10 | .742 | 59.2 | .083 | 9.0 | 74.5 | 70.1 | 96 | 114 | 132 | 163 | 192 | 243 | 292 | 348 | 369 | 403 | 1.0 | 1.8 | 10 | | | |
| Average | 0.747 | 57.9 | 0.066 | 8.3 | 74.8 | 69.9 | 97 | 116 | 137 | 168 | 198 | 248 | 294 | 351 | 374 | 406 | 1.0 | 2.1 | Average | | | |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|-----|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 11 | 0.744 | 58.6 | 0.063 | 8.1 | 81.0 | 75.0 | 96 | 121 | 142 | 172 | 200 | 244 | 290 | 349 | 372 | 404 | 1.0 | 1.5 | 11 |
| 12 | .747 | 57.9 | .100 | 7.6 | 80.5 | 73.0 | 98 | 128 | 146 | 176 | 204 | 254 | 298 | 350 | 372 | 398 | 1.0 | 1.0 | 12 |
| Average | 0.746 | 58.3 | 0.082 | 7.9 | 80.8 | 74.0 | 97 | 125 | 144 | 174 | 202 | 249 | 294 | 350 | 372 | 401 | 1.0 | 1.3 | Average |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Chicago (Ill.) area: includes cities in northern Illinois, northern Indiana, and southern Wisconsin

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | | Percent | | Item | |
|---------|-------------------------|-----------------|-------------|---------------|----------|------|----|-----|-----|-----|-----|-----------|-----|-----|-----|---------|------|------|---------|
| | Percent evaporated | | | | | | | | | | | | | | | Residue | Loss | | |
| | I.B.P. | 10 | | | | | 50 | | | | | End point | | | | | | | |
| | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | | | | | | | |
| | Gravity | Sulfur, percent | R.V.P., lb. | Octane number | | | | | | | | | | | | | | | |
| | Specific | A.P.I. | | Research | A.S.T.M. | | | | | | | | | | | | | | |
| 1 | 0.737 | 60.5 | 0.100 | 11.1 | 73.5 | 69.9 | 88 | 102 | 125 | 160 | 194 | 253 | 293 | 349 | 374 | 401 | 1.0 | 3.1 | 1 |
| 2 | .725 | 63.6 | .066 | 11.4 | 72.7 | 69.6 | 89 | 100 | 117 | 142 | 168 | 225 | 278 | 342 | 368 | 396 | .7 | 2.8 | 2 |
| 3 | .731 | 62.1 | .052 | 9.0 | 73.8 | 70.2 | 98 | 114 | 127 | 151 | 177 | 236 | 291 | 348 | 371 | 400 | .8 | 1.4 | 3 |
| 4 | .730 | 62.3 | .032 | 11.1 | 73.4 | 70.1 | 88 | 100 | 117 | 143 | 172 | 232 | 285 | 345 | 366 | 391 | .7 | 2.7 | 4 |
| 5 | .731 | 62.0 | .050 | 11.0 | 74.0 | 70.3 | 88 | 99 | 119 | 150 | 180 | 238 | 285 | 346 | 371 | 402 | .6 | 2.9 | 5 |
| 6 | .732 | 61.7 | - | 10.7 | 72.9 | 69.5 | 90 | 103 | 126 | 159 | 193 | 247 | 289 | 343 | 371 | 401 | .6 | 3.1 | 6 |
| 7 | .731 | 62.0 | - | 10.4 | 72.9 | 70.1 | 89 | 105 | 124 | 153 | 183 | 240 | 287 | 344 | 369 | 402 | .7 | 2.3 | 7 |
| 8 | .730 | 62.3 | - | 10.0 | 73.3 | 70.2 | 92 | 107 | 126 | 154 | 184 | 241 | 291 | 347 | 370 | 404 | .7 | 2.3 | 8 |
| 9 | .732 | 61.9 | .042 | 9.9 | 73.2 | 70.4 | 95 | 110 | 131 | 160 | 186 | 234 | 280 | 346 | 372 | 404 | .9 | 2.2 | 9 |
| 10 | .730 | 62.4 | .052 | 11.1 | 72.2 | 69.7 | 88 | 99 | 121 | 151 | 180 | 236 | 284 | 343 | 370 | 405 | .8 | 3.3 | 10 |
| 11 | .731 | 62.1 | .096 | 11.4 | 74.5 | 70.3 | 86 | 96 | 113 | 142 | 176 | 238 | 288 | 345 | 368 | 406 | .8 | 3.2 | 11 |
| 12 | .722 | 64.4 | - | 11.5 | 69.8 | 69.6 | 90 | 99 | 115 | 141 | 170 | 226 | 280 | 342 | 363 | 392 | .9 | 3.2 | 12 |
| 13 | .738 | 60.3 | - | 11.8 | 76.0 | 71.3 | 87 | 95 | 116 | 148 | 184 | 248 | 303 | 367 | 387 | 407 | .5 | 4.1 | 13 |
| 14 | .733 | 61.6 | - | - | - | 70.9 | - | - | - | - | - | - | - | - | - | - | - | - | 14 |
| Average | 0.731 | 62.1 | 0.061 | 10.8 | 73.2 | 70.2 | 90 | 102 | 121 | 150 | 181 | 238 | 287 | 347 | 371 | 401 | 0.7 | 2.8 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 15 | 0.731 | 62.1 | 0.097 | 10.7 | 79.4 | 74.2 | 90 | 105 | 121 | 146 | 172 | 229 | 281 | 344 | 371 | 394 | 0.8 | 2.2 | 15 |
| 16 | .740 | 59.8 | .151 | 10.3 | 83.0 | 75.5 | 91 | 106 | 125 | 156 | 188 | 242 | 289 | 347 | 372 | 404 | 1.0 | 2.4 | 16 |
| 17 | .729 | 62.7 | .058 | 10.4 | 81.0 | 75.4 | 92 | 105 | 117 | 139 | 164 | 224 | 290 | 350 | 371 | 395 | .9 | 1.8 | 17 |
| 18 | .732 | 61.9 | .058 | 10.1 | 81.4 | 75.7 | 90 | 105 | 122 | 150 | 179 | 232 | 278 | 342 | 369 | 404 | .9 | 2.1 | 18 |
| 19 | .729 | 62.6 | .035 | 10.8 | 78.8 | 74.9 | 90 | 103 | 119 | 143 | 169 | 227 | 282 | 343 | 364 | 388 | .8 | 1.9 | 19 |
| 20 | .734 | 61.3 | .128 | 11.1 | 79.9 | 74.4 | 87 | 99 | 114 | 144 | 178 | 238 | 285 | 343 | 368 | 403 | 1.1 | 2.6 | 20 |
| 21 | .736 | 60.8 | .090 | 10.5 | 82.1 | 75.3 | 88 | 104 | 123 | 154 | 187 | 243 | 288 | 345 | 372 | 401 | 1.0 | 2.3 | 21 |
| 22 | .734 | 61.4 | .044 | 10.2 | 79.8 | 75.3 | 91 | 106 | 127 | 157 | 183 | 229 | 277 | 341 | 366 | 400 | .9 | 2.3 | 22 |
| 23 | .722 | 64.4 | - | 13.3 | 75.8 | 73.6 | 83 | 88 | 107 | 134 | 164 | 220 | 278 | 371 | 413 | 455 | .7 | 4.3 | 23 |
| 24 | .742 | 59.3 | - | 9.6 | 83.0 | 75.5 | 87 | 104 | 119 | 151 | 186 | 242 | 284 | 337 | 361 | 391 | .5 | 2.5 | 24 |
| 25 | .732 | 61.7 | - | - | 81.3 | 76.3 | - | - | - | - | - | - | - | - | - | - | - | - | 25 |
| Average | 0.733 | 61.6 | 0.083 | 10.7 | 80.5 | 75.1 | 89 | 103 | 119 | 147 | 177 | 233 | 283 | 346 | 373 | 404 | 0.9 | 2.4 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | | | |
|----|-------|------|---|------|---|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 26 | 0.722 | 64.6 | - | 10.2 | - | 55.4 | 92 | 105 | 120 | 142 | 163 | 210 | 301 | 353 | 376 | 423 | 0.8 | 1.7 | 26 |
|----|-------|------|---|------|---|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

New Orleans (La.) area; includes other cities in Louisiana

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | | Percent | | Item | | |
|---------|-------------------------|--------------------|----------------|---------------|------|--------|--------------------|--------|----------|----------|-----|-----|-----|-----|--------------|---------|-----|------|---------|----|
| | Gravity | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Percent evaporated | | | | | | | | End point | | | | | |
| | | | | | | | Specific | A.P.I. | Research | A.S.T.M. | 5 | 10 | 20 | 30 | | 50 | 70 | | 90 | 95 |
| | | | | | | | | | | | | | | | | | | | | |
| 1 | 0.743 | 58.9 | 0.070 | 8.5 | 75.0 | 70.0 | 94 | 115 | 135 | 165 | 192 | 236 | 275 | 334 | 360 | 398 | 1.0 | 1.5 | 1 | |
| 2 | .746 | 58.1 | .045 | 8.6 | 75.6 | 69.9 | 93 | 118 | 138 | 172 | 203 | 252 | 294 | 355 | 380 | 411 | 1.0 | 1.3 | 2 | |
| 3 | .737 | 60.4 | .055 | 8.5 | 73.0 | 70.0 | 92 | 113 | 132 | 160 | 184 | 231 | 273 | 341 | 375 | 398 | 1.5 | 1.5 | 3 | |
| 4 | .746 | 58.1 | .043 | 9.1 | 74.7 | 70.6 | 93 | 109 | 129 | 163 | 197 | 252 | 297 | 350 | 371 | 398 | .8 | 2.0 | 4 | |
| 5 | .754 | 56.1 | .054 | 7.0 | 73.6 | 70.3 | 99 | 121 | 143 | 178 | 208 | 258 | 302 | 362 | 387 | 418 | 1.1 | 1.5 | 5 | |
| 6 | .745 | 58.4 | .084 | 7.2 | 73.9 | 70.0 | 98 | 120 | 139 | 171 | 199 | 242 | 288 | 343 | 366 | 395 | .9 | 1.3 | 6 | |
| Average | 0.746 | 58.3 | 0.059 | 8.2 | 74.3 | 70.1 | 95 | 116 | 136 | 168 | 197 | 245 | 288 | 348 | 373 | 403 | 1.1 | 1.5 | Average | |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 7 | 0.749 | 57.5 | 0.049 | 8.3 | 83.0 | 75.0 | 96 | 118 | 141 | 171 | 200 | 251 | 292 | 351 | 376 | 408 | 1.0 | 1.5 |
| 8 | .747 | 58.0 | .047 | 8.2 | 82.2 | 75.2 | 97 | 114 | 133 | 163 | 192 | 243 | 289 | 352 | 376 | 411 | 1.0 | 2.0 |
| 9 | .754 | 56.2 | .039 | 9.2 | 79.0 | 74.0 | 95 | 114 | 135 | 171 | 205 | 258 | 301 | 355 | 377 | 404 | 1.0 | 2.0 |
| 10 | .752 | 56.6 | .042 | 8.8 | 80.8 | 75.0 | 92 | 106 | 123 | 158 | 193 | 251 | 296 | 348 | 369 | 396 | 1.0 | 2.0 |
| 11 | .754 | 56.2 | .067 | 7.1 | 83.0 | 76.0 | 106 | 127 | 149 | 181 | 208 | 255 | 301 | 356 | 380 | 412 | 1.0 | 1.5 |
| 12 | .750 | 57.1 | .080 | 7.2 | 81.1 | 75.1 | 98 | 118 | 138 | 173 | 205 | 258 | 303 | 354 | 376 | 404 | .9 | 1.6 |
| Average | 0.751 | 56.9 | 0.054 | 8.1 | 81.5 | 75.1 | 97 | 116 | 137 | 170 | 201 | 253 | 297 | 353 | 376 | 406 | 1.0 | 1.8 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)
Memphis (Tenn.) area: includes cities in Tennessee and North Carolina

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | | Percent | | Item | |
|---------|-------------------------|------|--------------------|----------------|---------------------------|------|----------|--------|--------------------|-----|-----|-----|-----|-----|--------------|---------|------|------|---------|
| | Gravity Specific | | Sulfur, percent | R.V.P., lb. | Octane number Research | | A.S.T.M. | I.B.P. | Percent evaporated | | | | | | End point | Residue | Loss | | |
| | | | | | | | | | Percent evaporated | | | | | | | | | | |
| | | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | | | | | 90 |
| 1 | 0.745 | 58.4 | 0.087 | 8.7 | 74.7 | 69.8 | 98 | 119 | 138 | 170 | 200 | 253 | 295 | 350 | 372 | 405 | 0.8 | 1.5 | 1 |
| 2 | .745 | 58.5 | .070 | 8.9 | 76.0 | 70.0 | 99 | 118 | 139 | 168 | 199 | 250 | 296 | 350 | 371 | 410 | 1.0 | 2.0 | 2 |
| 3 | .744 | 58.7 | .076 | 7.5 | 75.9 | 70.1 | 98 | 115 | 136 | 166 | 194 | 244 | 293 | 349 | 369 | 400 | 1.0 | 2.4 | 3 |
| 4 | .750 | 57.2 | .026 | 8.9 | 75.5 | 70.1 | 91 | 109 | 138 | 172 | 207 | 254 | 299 | 351 | 370 | 393 | 1.0 | 2.5 | 4 |
| 5 | .746 | 58.1 | .097 | 8.2 | 76.0 | 70.8 | 95 | 113 | 133 | 165 | 197 | 250 | 294 | 347 | 369 | 408 | 1.0 | 1.7 | 5 |
| 6 | .755 | 55.9 | .104 | 8.0 | 76.6 | 71.2 | 98 | 115 | 136 | 173 | 209 | 262 | 304 | 358 | 382 | 420 | .9 | 1.5 | 6 |
| Average | 0.748 | 57.8 | 0.077 | 8.4 | 75.8 | 70.3 | 97 | 115 | 137 | 169 | 201 | 252 | 297 | 351 | 372 | 406 | 1.0 | 1.9 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 7 | 0.754 | 56.2 | 0.090 | 7.5 | 80.9 | 75.5 | 94 | 120 | 143 | 162 | 212 | 263 | 304 | 358 | 386 | 446 | 0.9 | 1.1 | 7 |
| 8 | .753 | 56.4 | .085 | 7.2 | 81.5 | 75.2 | 100 | 123 | 141 | 176 | 205 | 254 | 298 | 348 | 372 | 403 | 1.0 | 1.0 | 8 |
| 9 | .752 | 56.7 | .028 | 8.7 | 82.6 | 75.6 | 91 | 111 | 134 | 166 | 199 | 252 | 298 | 352 | 372 | 399 | 1.0 | 2.0 | 9 |
| Average | 0.753 | 56.4 | 0.068 | 7.8 | 81.7 | 75.4 | 95 | 118 | 139 | 168 | 205 | 256 | 300 | 353 | 377 | 416 | 1.0 | 1.4 | Average |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)
St. Louis (Mo.) area: includes cities in eastern Missouri, southern Illinois, southern Indiana, and Kentucky

Regular-price gasoline

| Item | Gravity | Sulfur, percent | R.V.P., lb. | Octane number | | Distillation range, F. | | | | | | | | | | Percent | | Item |
|---------|---------|--------------------|----------------|---------------|----------|------------------------|-----|-----|------|-----|-----|-----|-----|---------|------|---------|--------------|------|
| | | | | Research | A.S.T.M. | Percent evaporated | | | | | | | | Residue | Loss | | | |
| | | | | | | I.B.P. | 5 | 10 | 20 | 30 | 50 | 70 | 90 | | | 95 | End point | |
| 1 | 0.720 | 0.050 | 11.1 | 72.7 | 70.1 | 90 | 100 | 115 | 14.0 | 164 | 218 | 273 | 341 | 368 | 0.7 | 2.8 | 1 | |
| 2 | .733 | .047 | 10.2 | 71.1 | 69.4 | 94 | 107 | 128 | 160 | 191 | 243 | 287 | 342 | 365 | .8 | 2.7 | 2 | |
| 3 | .732 | .039 | 10.5 | 71.4 | 69.4 | 92 | 106 | 128 | 162 | 194 | 247 | 291 | 345 | 368 | .8 | 2.8 | 3 | |
| 4 | .735 | .085 | 10.2 | 73.9 | 69.8 | 92 | 106 | 126 | 159 | 189 | 242 | 288 | 345 | 371 | 1.0 | 2.7 | 4 | |
| 5 | .723 | .041 | 10.6 | 72.6 | 69.9 | 91 | 104 | 119 | 141 | 165 | 220 | 276 | 344 | 370 | .8 | 2.1 | 5 | |
| 6 | .739 | - | 8.6 | 75.4 | 71.1 | 96 | 117 | 134 | 164 | 193 | 245 | 292 | 350 | 371 | .7 | 1.9 | 6 | |
| 7 | .736 | .043 | 10.0 | 73.0 | 69.6 | 92 | 107 | 128 | 162 | 193 | 245 | 291 | 348 | 369 | .8 | 2.5 | 7 | |
| 8 | .737 | - | 9.9 | 74.6 | 69.5 | 93 | 110 | 132 | 164 | 191 | 235 | 277 | 331 | 355 | .6 | 2.8 | 8 | |
| 9 | .736 | - | 10.2 | 74.9 | 70.0 | 90 | 103 | 122 | 154 | 187 | 243 | 288 | 342 | 365 | .7 | 2.9 | 9 | |
| 10 | .734 | - | 8.9 | 70.1 | 68.9 | 95 | 117 | 139 | 172 | 200 | 248 | 293 | 345 | 366 | .7 | 2.3 | 10 | |
| 11 | .739 | - | 9.8 | 74.4 | 69.6 | 91 | 106 | 124 | 157 | 192 | 247 | 287 | 341 | 368 | .7 | 2.4 | 11 | |
| 12 | .734 | - | 10.2 | 75.9 | 69.9 | 89 | 104 | 122 | 153 | 194 | 250 | 293 | 347 | 368 | .5 | 2.8 | 12 | |
| 13 | .726 | - | 11.6 | 74.2 | 69.4 | 87 | 96 | 118 | 151 | 182 | 236 | 277 | 336 | 363 | .7 | 3.8 | 13 | |
| 14 | .746 | - | 8.7 | 74.9 | 70.4 | 96 | 113 | 132 | 161 | 194 | 251 | 294 | 346 | 369 | .5 | 2.0 | 14 | |
| 15 | .741 | - | 10.9 | 75.6 | 70.2 | 91 | 103 | 125 | 163 | 200 | 260 | 298 | 350 | 374 | .9 | 3.3 | 15 | |
| 16 | .721 | - | 11.7 | 75.2 | 68.4 | 91 | 99 | 114 | 143 | 171 | 220 | 258 | 313 | 340 | .9 | 3.1 | 16 | |
| 17 | .746 | .136 | 8.8 | 75.3 | 68.5 | 97 | 108 | 119 | 145 | 171 | 225 | 279 | 347 | 370 | 1.0 | 2.0 | 17 | |
| 18 | .735 | .051 | 9.8 | 74.3 | 69.9 | 102 | 128 | 146 | 175 | 202 | 252 | 298 | 354 | 378 | 1.0 | 1.2 | 18 | |
| 19 | .749 | - | 8.3 | - | 70.3 | 90 | 107 | 128 | 157 | 187 | 240 | 292 | 349 | 369 | .8 | 2.6 | 19 | |
| 20 | .739 | - | 8.4 | - | 70.0 | 96 | 114 | 131 | 157 | 183 | 229 | 275 | 338 | 360 | 1.0 | 2.0 | 20 | |
| 21 | .738 | - | 8.2 | - | 70.8 | 99 | 127 | 149 | 182 | 210 | 252 | 285 | 329 | 345 | .8 | 2.2 | 21 | |
| 22 | .731 | - | - | - | 69.9 | 89 | 96 | 113 | 145 | 180 | 239 | 295 | 360 | 382 | 1.0 | 3.0 | 22 | |
| 23 | .722 | - | - | - | 70.2 | - | - | - | - | - | - | - | - | - | - | - | 23 | |
| 24 | .750 | - | - | - | 70.9 | - | - | - | - | - | - | - | - | - | - | - | 24 | |
| Average | 0.735 | 0.062 | 9.8 | 73.9 | 69.8 | 93 | 108 | 127 | 158 | 188 | 240 | 286 | 343 | 366 | 0.8 | 2.5 | Average | |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 25 | 0.726 | 63.5 | 0.106 | 10.1 | 79.1 | 74.9 | 92 | 107 | 121 | 143 | 163 | 215 | 275 | 342 | 367 | 0.8 | 1.6 | 25 |
| 26 | .731 | 62.1 | .044 | 9.9 | 78.3 | 75.2 | 95 | 110 | 131 | 161 | 188 | 236 | 280 | 337 | 361 | 1.0 | 2.2 | 26 |
| 27 | .735 | 61.0 | .052 | 10.0 | 79.6 | 75.2 | 91 | 104 | 128 | 161 | 193 | 245 | 289 | 345 | 367 | .8 | 3.3 | 27 |
| 28 | .734 | 61.2 | .089 | 8.7 | 80.6 | 75.4 | 94 | 111 | 125 | 148 | 170 | 223 | 276 | 343 | 368 | .9 | 1.5 | 28 |
| 29 | .736 | 60.9 | .101 | 9.3 | 82.4 | 75.3 | 94 | 110 | 128 | 155 | 183 | 239 | 289 | 347 | 370 | .9 | 2.0 | 29 |
| 30 | .737 | 60.4 | .047 | 9.5 | 80.5 | 75.2 | 96 | 110 | 130 | 162 | 193 | 241 | 286 | 343 | 366 | .9 | 2.4 | 30 |
| 31 | .733 | 61.5 | .053 | 10.3 | 81.2 | 75.1 | 104 | 109 | 122 | 149 | 175 | 222 | 275 | 332 | 362 | 1.0 | 3.5 | 31 |
| 32 | .728 | 63.0 | - | 10.2 | 80.0 | 74.8 | 91 | 108 | 127 | 155 | 180 | 222 | 261 | 321 | 350 | .8 | 2.4 | 32 |
| 33 | .732 | 61.8 | - | - | - | 75.6 | - | - | - | - | - | - | - | - | - | - | - | 33 |
| 34 | .742 | 59.1 | .073 | 7.4 | - | 75.2 | 96 | 126 | 145 | 178 | 210 | 255 | 296 | 346 | 366 | 1.1 | 1.9 | 34 |
| 35 | .727 | 63.2 | - | 11.4 | 82.8 | 76.4 | 90 | 102 | 120 | 148 | 174 | 225 | 270 | 324 | 356 | .4 | 2.6 | 35 |
| 36 | .739 | 60.0 | - | - | - | 76.1 | - | - | - | - | - | - | - | - | - | - | - | 36 |
| 37 | .734 | 61.3 | .053 | 8.3 | 80.0 | 75.5 | 104 | 125 | 141 | 172 | 199 | 245 | 285 | 337 | 358 | 1.0 | 1.3 | 37 |
| 38 | .736 | 60.7 | .076 | 8.7 | 81.5 | 75.1 | 99 | 121 | 139 | 169 | 201 | 254 | 301 | 357 | 376 | 1.0 | 1.2 | 38 |
| 39 | .748 | 57.7 | .030 | 9.1 | - | 76.3 | 91 | 110 | 127 | 156 | 187 | 243 | 295 | 352 | 373 | 1.0 | 2.0 | 39 |
| 40 | .742 | 59.3 | .062 | 8.5 | - | 75.3 | 98 | 123 | 141 | 170 | 196 | 242 | 289 | 344 | 366 | 1.2 | 1.8 | 40 |
| 41 | .739 | 59.9 | - | 9.3 | - | 75.9 | 94 | 113 | 130 | 159 | 185 | 232 | 280 | 341 | 363 | .9 | 2.1 | 41 |
| 42 | .734 | 61.4 | .034 | 9.5 | - | 75.8 | 90 | 110 | 133 | 167 | 197 | 245 | 290 | 340 | 358 | .8 | 2.4 | 42 |
| 43 | .722 | 64.5 | - | - | - | 76.0 | - | - | - | - | - | - | - | - | - | - | - | 43 |
| Average | 0.734 | 61.2 | 0.063 | 9.4 | 80.5 | 75.5 | 95 | 112 | 131 | 160 | 187 | 237 | 284 | 341 | 364 | 0.9 | 2.1 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | | |
|----|-------|------|---|-----|---|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 44 | 0.734 | 61.2 | - | 6.0 | - | 54.4 | 109 | 138 | 155 | 180 | 201 | 242 | 286 | 347 | 370 | 0.8 | 1.4 | 44 |
| 45 | .724 | 64.0 | - | 7.7 | - | 53.8 | 103 | 118 | 132 | 151 | 173 | 230 | 280 | 342 | 366 | .5 | 2.0 | 45 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Distillation range, °F. | | | | | | | Percent | | Item | | |
|---------|----------|---------|--------------------|----------------|---------------|----------|--------|-------------------------|-----|-----|-----|-----|-----|-----|---------|------|------|-----|---------|
| | Specific | °A.P.I. | | | Research | A.S.T.M. | | Percent evaporated | | | | | | | Residue | Loss | | | |
| | | | | | | | | End | | | | | | | | | | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | | | | 95 | point |
| 1 | 0.730 | 62.4 | 0.092 | 9.6 | 73.6 | 70.1 | 92 | 110 | 128 | 155 | 181 | 234 | 284 | 345 | 367 | 399 | 0.9 | 1.8 | 1 |
| 2 | .726 | 63.3 | .052 | 9.9 | 73.2 | 70.4 | 91 | 106 | 122 | 148 | 173 | 226 | 279 | 341 | 365 | 405 | .9 | 2.1 | 2 |
| 3 | .729 | 62.5 | .059 | 9.2 | 74.3 | 70.9 | 92 | 113 | 129 | 158 | 186 | 239 | 286 | 344 | 366 | 397 | .8 | 1.9 | 3 |
| 4 | .732 | 61.7 | .072 | 9.4 | 72.8 | 70.0 | 96 | 113 | 128 | 155 | 183 | 235 | 284 | 344 | 370 | 401 | .8 | 1.7 | 4 |
| 5 | .728 | 62.9 | .046 | 9.7 | 73.0 | 70.4 | 96 | 111 | 128 | 154 | 180 | 232 | 283 | 345 | 373 | 402 | 1.0 | 1.6 | 5 |
| 6 | .730 | 62.3 | .066 | 8.8 | 73.5 | 70.3 | 91 | 112 | 130 | 160 | 187 | 238 | 283 | 341 | 363 | 400 | .9 | 2.1 | 6 |
| 7 | .727 | 63.1 | - | 10.2 | 73.5 | 70.5 | 93 | 106 | 124 | 150 | 175 | 228 | 281 | 343 | 369 | 399 | .8 | 2.2 | 7 |
| 8 | .730 | 62.4 | - | 10.3 | 73.5 | 70.5 | 90 | 101 | 120 | 144 | 169 | 226 | 278 | 340 | 365 | 397 | .6 | 2.4 | 8 |
| 9 | .731 | 62.0 | - | 10.2 | 73.4 | 70.2 | 95 | 107 | 125 | 152 | 180 | 234 | 280 | 344 | 369 | 400 | .8 | 1.9 | 9 |
| 10 | .727 | 63.2 | - | 10.2 | 73.3 | 70.4 | 93 | 107 | 124 | 150 | 177 | 230 | 282 | 347 | 373 | 403 | .7 | 1.9 | 10 |
| 11 | .728 | 62.8 | - | 9.9 | 73.0 | 70.3 | 93 | 107 | 123 | 150 | 177 | 229 | 280 | 344 | 369 | 397 | .7 | 2.3 | 11 |
| 12 | .728 | 63.0 | - | 10.1 | 73.4 | 70.2 | 91 | 108 | 124 | 149 | 173 | 228 | 282 | 346 | 371 | 403 | .6 | 2.0 | 12 |
| 13 | .729 | 62.5 | - | 9.6 | 74.2 | 70.4 | 92 | 110 | 127 | 153 | 179 | 232 | 282 | 341 | 369 | 401 | .8 | 2.2 | 13 |
| Average | 0.729 | 62.6 | 0.065 | 9.8 | 73.4 | 70.4 | 93 | 109 | 126 | 152 | 178 | 232 | 282 | 343 | 368 | 400 | 0.8 | 2.0 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 14 | 0.727 | 63.1 | 0.053 | 9.9 | 79.4 | 74.9 | 92 | 108 | 124 | 148 | 173 | 226 | 278 | 341 | 366 | 404 | 0.9 | 2.2 | 14 |
| 15 | .727 | 63.1 | .053 | 9.5 | 79.9 | 75.3 | 91 | 107 | 125 | 150 | 175 | 229 | 280 | 340 | 368 | 401 | .9 | 1.6 | 15 |
| 16 | .727 | 63.1 | .053 | 9.7 | 80.2 | 75.7 | 94 | 110 | 124 | 149 | 173 | 226 | 278 | 346 | 375 | 402 | .8 | 1.4 | 16 |
| 17 | .739 | 59.9 | .169 | 8.4 | 78.3 | 74.7 | 95 | 113 | 130 | 162 | 192 | 245 | 297 | 359 | 380 | 413 | .9 | 1.8 | 17 |
| 18 | .727 | 63.2 | .059 | 9.7 | 79.9 | 75.4 | 91 | 111 | 124 | 148 | 172 | 225 | 278 | 341 | 368 | 401 | .8 | 2.0 | 18 |
| 19 | .734 | 61.4 | .046 | 9.3 | 79.8 | 75.5 | 96 | 113 | 130 | 153 | 177 | 226 | 277 | 343 | 372 | 408 | .9 | 2.1 | 19 |
| 20 | .707 | 68.7 | - | - | 74.0 | 73.6 | - | - | - | - | - | - | - | - | - | - | - | - | 20 |
| 21 | .729 | 62.6 | - | - | 78.0 | 74.1 | - | - | - | - | - | - | - | - | - | - | - | - | 21 |
| 22 | .726 | 63.3 | - | 10.1 | 79.1 | 75.0 | 93 | 109 | 125 | 149 | 174 | 229 | 283 | 345 | 371 | 402 | .8 | 1.8 | 22 |
| Average | 0.727 | 63.2 | 0.072 | 9.7 | 78.7 | 74.9 | 93 | 110 | 126 | 151 | 177 | 229 | 282 | 345 | 371 | 404 | 0.9 | 1.8 | Average |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)
Omaha (Nebr.) area; includes Kansas City, Mo., and cities in Iowa and Nebraska

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | | Percent | | Item | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|------|-------------------------|--------------------|----------------|---------------|--|--------------------|---|--|--|--|--|----|--|--|--|--------------|---------|------|------|----|--|--|--|--|----|--|--|--|--|----|--|--|--|--|----|--|--|--|--|----|--|--|--|--|----|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
| | Gravity Specific | Sulfur, percent | R.V.P., lb. | Octane number | | Percent evaporated | | | | | | | | | | End point | Residue | | Loss | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | I.B.P. | 5 | | | | | 10 | | | | | | | | 20 | | | | | 30 | | | | | 50 | | | | | 70 | | | | | 90 | | | | | 95 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 17 | 0.729 | 62.7 | 0.029 | 9.8 | 80.9 | 75.6 | 99 | 117 | 132 | 152 | 171 | 219 | 269 | 334 | 362 | 0.8 | 1.8 |
| 18 | .728 | 62.9 | - | 9.3 | 82.8 | 75.7 | 99 | 116 | 131 | 155 | 178 | 226 | 265 | 310 | 329 | .7 | 1.8 |
| 19 | .721 | 64.8 | - | 11.5 | 80.1 | 75.3 | 89 | 98 | 115 | 144 | 173 | 226 | 271 | 324 | 346 | .8 | 3.2 |
| 20 | .734 | 61.2 | .048 | 8.5 | 80.8 | 75.8 | 99 | 117 | 132 | 160 | 187 | 237 | 287 | 348 | 370 | 1.0 | 1.5 |
| 21 | .728 | 63.0 | .054 | 12.0 | 80.9 | 75.6 | 93 | 99 | 120 | 150 | 178 | 227 | 273 | 333 | 354 | .8 | 3.8 |
| 22 | .729 | 62.5 | .045 | 9.7 | 80.1 | 75.7 | 101 | 114 | 129 | 154 | 179 | 231 | 281 | 347 | 374 | .8 | 1.9 |
| 23 | .726 | 63.4 | - | 9.8 | 79.4 | 75.0 | 92 | 110 | 124 | 145 | 171 | 227 | 279 | 339 | 363 | .8 | 2.1 |
| 24 | .711 | 67.4 | - | 13.7 | 77.9 | 75.4 | 87 | 90 | 104 | 125 | 148 | 202 | 262 | 334 | 364 | .9 | 4.1 |
| 25 | .723 | 64.3 | .107 | 10.4 | 82.5 | 76.1 | 101 | 112 | 124 | 148 | 171 | 215 | 257 | 318 | 349 | 1.0 | 2.7 |
| 26 | .733 | 61.6 | .041 | 11.7 | 76.2 | 74.1 | 104 | 123 | 137 | 158 | 175 | 215 | 266 | 343 | 381 | 1.0 | 2.4 |
| Average | 0.726 | 63.4 | 0.054 | 10.6 | 80.2 | 75.4 | 96 | 110 | 125 | 149 | 173 | 223 | 271 | 333 | 359 | 0.9 | 2.5 |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | |
|----|-------|------|---|-----|---|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 27 | 0.717 | 65.9 | - | 7.6 | - | 53.6 | 105 | 128 | 148 | 173 | 192 | 221 | 247 | 289 | 312 | 0.2 | 1.7 |
| 28 | .723 | 64.2 | - | 6.5 | - | 47.5 | 102 | 133 | 154 | 184 | 209 | 249 | 282 | 335 | 367 | .8 | .4 |
| 29 | .731 | 62.2 | - | 7.3 | - | 51.8 | 103 | 130 | 148 | 176 | 203 | 250 | 292 | 347 | 374 | .8 | 1.4 |
| 30 | .742 | 59.2 | - | 6.5 | - | 60.6 | 107 | 138 | 160 | 191 | 220 | 260 | 293 | 346 | 376 | .9 | 1.1 |
| 31 | .729 | 62.5 | - | 6.8 | - | 50.2 | 105 | 136 | 152 | 176 | 199 | 243 | 290 | 358 | 387 | .6 | .9 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Tulsa (Okla.) area: includes cities in Oklahoma, Arkansas, and Kansas

Regular-price gasoline

| Item | Gravity Specific | Sulfur, percent | R.V.P., lb. | Octane number Research | A.S.T.M. | Distillation range, °F. | | | | | | | | | | Percent | | Item |
|---------|---------------------|--------------------|----------------|---------------------------|----------|-------------------------|--------------------|-----|-----|-----|-----|-----|--------------|---------|------|---------|---------|------|
| | | | | | | Percent evaporated | | | | | | | End point | Residue | Loss | | | |
| | | | | | | I.B.P. | Percent evaporated | | | | | | | | | | | |
| | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | | | | 90 | 95 | |
| 1 | 0.730 | 0.038 | 9.8 | 73.7 | 69.0 | 92 | 109 | 127 | 154 | 180 | 231 | 281 | 343 | 370 | 0.8 | 1.8 | 1 | |
| 2 | .734 | .087 | 8.1 | 73.0 | 69.0 | 95 | 112 | 130 | 148 | 180 | 241 | 298 | 352 | 371 | 1.0 | 1.5 | 2 | |
| 3 | .731 | .043 | 10.1 | 74.3 | 69.2 | 93 | 106 | 122 | 146 | 175 | 229 | 280 | 347 | 373 | 1.0 | 2.1 | 3 | |
| 4 | .725 | .047 | 9.3 | 71.9 | 69.4 | 93 | 111 | 127 | 152 | 177 | 227 | 276 | 337 | 360 | .8 | 1.9 | 4 | |
| 5 | .731 | .081 | 10.0 | 73.2 | 69.7 | 94 | 107 | 124 | 151 | 179 | 232 | 279 | 343 | 368 | .9 | 2.3 | 5 | |
| 6 | .729 | .046 | 8.3 | 73.0 | 69.9 | 97 | 115 | 134 | 159 | 183 | 234 | 288 | 345 | 365 | 1.0 | 1.8 | 6 | |
| 7 | .727 | .031 | 9.6 | 72.8 | 69.7 | 94 | 109 | 125 | 150 | 175 | 227 | 279 | 345 | 370 | .9 | 1.9 | 7 | |
| 8 | .736 | - | 8.9 | 73.4 | 70.0 | 95 | 113 | 133 | 164 | 193 | 246 | 289 | 342 | 365 | .9 | 2.1 | 8 | |
| 9 | .734 | - | 9.6 | 72.9 | 69.8 | 94 | 110 | 132 | 163 | 192 | 245 | 287 | 337 | 359 | .7 | 2.4 | 9 | |
| 10 | .730 | - | 11.3 | 76.2 | 71.2 | 88 | 100 | 123 | 155 | 185 | 235 | 281 | 342 | 365 | .4 | 3.6 | 10 | |
| 11 | .733 | - | 10.9 | 74.1 | 69.1 | 87 | 101 | 116 | 142 | 172 | 227 | 280 | 352 | 380 | .8 | 2.5 | 11 | |
| 12 | .733 | - | 8.7 | 69.1 | 67.3 | 93 | 117 | 139 | 173 | 201 | 245 | 285 | 336 | 359 | .5 | 2.1 | 12 | |
| 13 | .732 | - | 10.5 | 74.2 | 69.4 | 91 | 101 | 117 | 145 | 174 | 228 | 282 | 355 | 382 | 1.0 | 2.6 | 13 | |
| 14 | .734 | .054 | 8.8 | 72.5 | 69.4 | 97 | 118 | 136 | 167 | 196 | 247 | 293 | 347 | 369 | 1.0 | 1.6 | 14 | |
| 15 | .726 | .019 | 9.5 | 71.6 | 69.6 | 94 | 110 | 124 | 150 | 176 | 230 | 279 | 340 | 365 | .9 | 1.7 | 15 | |
| 16 | .732 | .038 | 9.2 | 73.2 | 69.9 | 93 | 109 | 128 | 158 | 189 | 242 | 288 | 340 | 361 | .9 | 2.0 | 16 | |
| 17 | .735 | .029 | 9.1 | - | 67.1 | 93 | 110 | 130 | 161 | 190 | 238 | 283 | 338 | 359 | 1.0 | 2.0 | 17 | |
| 18 | .721 | .066 | 10.8 | 72.3 | 69.6 | 96 | 107 | 120 | 143 | 167 | 215 | 261 | 325 | 360 | 1.0 | 3.0 | 18 | |
| 19 | .724 | .090 | 9.6 | 75.6 | 70.2 | 106 | 123 | 139 | 163 | 185 | 227 | 266 | 323 | 360 | 1.0 | 1.0 | 19 | |
| 20 | .725 | .042 | 14.1 | 70.5 | 70.2 | 98 | 104 | 120 | 150 | 182 | 244 | 305 | 372 | 395 | 1.0 | 4.5 | 20 | |
| 21 | .728 | .043 | 11.9 | 75.6 | 72.2 | 100 | 108 | 124 | 151 | 179 | 234 | 284 | 347 | 383 | 1.0 | 3.7 | 21 | |
| Average | 0.730 | 0.050 | 9.9 | 73.2 | 69.6 | 94 | 110 | 127 | 155 | 182 | 234 | 283 | 343 | 369 | 0.9 | 2.3 | Average | |

Premium-price gasoline

| | | | | | | | | | | | | | | | | |
|---------|-------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 22 | 0.729 | 0.048 | 9.4 | 79.9 | 75.3 | 112 | 129 | 151 | 174 | 224 | 274 | 341 | 368 | 0.9 | 1.9 | 22 |
| 23 | .731 | .045 | 9.9 | 79.7 | 75.2 | 109 | 125 | 148 | 174 | 223 | 270 | 339 | 369 | 1.0 | 1.9 | 23 |
| 24 | .734 | .029 | 9.2 | 79.0 | 74.8 | 119 | 136 | 162 | 187 | 234 | 279 | 340 | 370 | .9 | 2.0 | 24 |
| 25 | .732 | .089 | 8.7 | 76.8 | 73.8 | 114 | 131 | 158 | 188 | 238 | 285 | 345 | 371 | 1.0 | 1.5 | 25 |
| 26 | .728 | .049 | 8.1 | 82.0 | 75.9 | 118 | 135 | 159 | 181 | 228 | 278 | 336 | 358 | 1.1 | 1.2 | 26 |
| 27 | .731 | .046 | 9.1 | 81.3 | 74.7 | 114 | 131 | 154 | 178 | 226 | 277 | 342 | 369 | .9 | 1.6 | 27 |
| 28 | .733 | - | 9.5 | 79.2 | 75.1 | 103 | 124 | 154 | 184 | 242 | 293 | 345 | 365 | .9 | 3.6 | 28 |
| 29 | .731 | - | 10.2 | 80.5 | 75.8 | 107 | 126 | 156 | 185 | 240 | 285 | 346 | 360 | .7 | 2.6 | 29 |
| 30 | .728 | - | 10.4 | 80.0 | 75.6 | 105 | 120 | 147 | 172 | 220 | 269 | 342 | 373 | .8 | 1.9 | 30 |
| 31 | .732 | - | 10.4 | 79.3 | 74.8 | 107 | 130 | 163 | 192 | 244 | 289 | 344 | 367 | 1.0 | 2.6 | 31 |
| 32 | .730 | .062 | 9.2 | 80.8 | 75.6 | 115 | 129 | 155 | 181 | 227 | 273 | 331 | 354 | .9 | 1.7 | 32 |
| 33 | .723 | .030 | 8.8 | 80.3 | 75.7 | 104 | 118 | 142 | 165 | 218 | 270 | 337 | 361 | 1.0 | 2.0 | 33 |
| 34 | .734 | .057 | 8.0 | 80.8 | 75.5 | 118 | 138 | 167 | 195 | 242 | 281 | 332 | 358 | 1.0 | 2.0 | 34 |
| 35 | .726 | .096 | 12.3 | 82.9 | 74.8 | 107 | 117 | 141 | 168 | 227 | 287 | 348 | 376 | 1.0 | 3.5 | 35 |
| 36 | .727 | .089 | 9.5 | 83.1 | 76.1 | 125 | 138 | 159 | 181 | 233 | 287 | 348 | 369 | .9 | .9 | 36 |
| 37 | .728 | .050 | 11.1 | 82.9 | 77.2 | 106 | 122 | 146 | 176 | 238 | 290 | 349 | 380 | 1.0 | 2.0 | 37 |
| Average | 0.730 | 0.058 | 9.6 | 80.5 | 75.4 | 111 | 128 | 154 | 180 | 232 | 280 | 341 | 367 | 0.9 | 2.1 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | |
|----|-------|------|---|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 38 | 0.729 | 62.5 | - | 8.5 | 52.4 | 97 | 117 | 136 | 166 | 258 | 300 | 344 | 365 | 0.8 | 1.7 | 38 |
| 39 | .734 | 61.4 | - | 6.7 | 49.9 | 100 | 131 | 147 | 173 | 247 | 298 | 371 | 400 | 1.1 | 1.0 | 39 |
| 40 | .724 | 63.9 | - | 7.4 | 53.1 | 97 | 121 | 137 | 165 | 238 | 278 | 325 | 340 | .6 | 1.2 | 40 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Texas area, except panhandle and western Texas

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Distillation range, °F. | | | | | | | | Percent | | Item | |
|---------|----------|---------|--------------------|----------------|---------------|----------|--------|-------------------------|-----|-----|-----|-----|-----|-----|-----|---------|------|------|--------------|
| | Specific | °A.P.I. | | | Research | A.S.T.M. | | Percent evaporated | | | | | | | | Residue | Loss | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | End point |
| 1 | 0.741 | 59.6 | 0.081 | 10.2 | - | 70.5 | 93 | 111 | 125 | 157 | 197 | 265 | 305 | 351 | 368 | 394 | 1.0 | 1.2 | 1 |
| 2 | .744 | 58.8 | .163 | 8.4 | 76.4 | 69.7 | 96 | 116 | 134 | 163 | 190 | 245 | 291 | 348 | 372 | 401 | 1.0 | 1.2 | 2 |
| 3 | .751 | 56.9 | .061 | 8.8 | 82.0 | 71.9 | 97 | 115 | 132 | 163 | 195 | 259 | 305 | 355 | 375 | 406 | 1.0 | 1.3 | 3 |
| 4 | .736 | 60.8 | .076 | 8.5 | 73.7 | 70.6 | 99 | 117 | 133 | 162 | 189 | 239 | 289 | 350 | 375 | 399 | 1.0 | 1.3 | 4 |
| 5 | .747 | 58.0 | .200 | 8.2 | 76.8 | 70.8 | 97 | 115 | 135 | 166 | 192 | 248 | 293 | 350 | 375 | 403 | 1.0 | 1.5 | 5 |
| 6 | .746 | 58.1 | .031 | 5.1 | - | 69.2 | 110 | 130 | 151 | 180 | 208 | 261 | 310 | 359 | 377 | 403 | 1.0 | 1.5 | 6 |
| 7 | .744 | 58.7 | .140 | 8.9 | - | 69.9 | 94 | 111 | 132 | 167 | 197 | 248 | 294 | 354 | 374 | 400 | 1.0 | 1.7 | 7 |
| 8 | .740 | 59.7 | .109 | 8.0 | 77.3 | 70.1 | 97 | 115 | 133 | 163 | 192 | 245 | 289 | 344 | 365 | 398 | 1.0 | 1.5 | 8 |
| 9 | .752 | 56.7 | .289 | 7.1 | - | 71.5 | 103 | 123 | 143 | 174 | 203 | 256 | 301 | 354 | 374 | 391 | 1.0 | 1.3 | 9 |
| Average | 0.744 | 58.6 | 0.128 | 8.1 | 77.2 | 70.5 | 98 | 117 | 135 | 166 | 196 | 252 | 297 | 352 | 373 | 399 | 1.0 | 1.4 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 10 | 0.742 | 59.3 | 0.084 | 9.7 | - | 76.8 | 95 | 113 | 126 | 161 | 196 | 258 | 302 | 349 | 366 | 389 | 1.0 | 1.6 | 10 |
| 11 | .747 | 57.9 | .167 | 8.4 | 80.2 | 74.1 | 94 | 117 | 135 | 166 | 197 | 254 | 300 | 354 | 375 | 403 | 1.0 | 1.0 | 11 |
| 12 | .750 | 57.2 | .098 | 8.6 | - | 75.7 | 98 | 113 | 132 | 168 | 202 | 258 | 306 | 359 | 377 | 405 | 1.0 | 2.0 | 12 |
| 13 | .734 | 61.3 | .074 | 7.8 | 81.7 | 75.3 | 95 | 107 | 127 | 157 | 185 | 235 | 283 | 343 | 365 | 393 | 1.0 | 2.0 | 13 |
| 14 | .748 | 57.6 | .148 | 7.3 | 83.4 | 74.8 | 100 | 118 | 135 | 161 | 186 | 241 | 285 | 343 | 367 | 398 | 1.0 | 1.5 | 14 |
| 15 | .713 | 66.9 | .016 | 9.0 | - | 75.1 | 95 | 108 | 126 | 150 | 173 | 217 | 264 | 325 | 352 | 386 | 1.0 | 1.5 | 15 |
| 16 | .743 | 58.9 | .136 | 8.9 | - | 75.5 | 94 | 109 | 130 | 165 | 199 | 248 | 296 | 353 | 375 | 402 | 1.0 | 2.0 | 16 |
| 17 | .744 | 58.8 | .074 | 8.5 | 83.6 | 76.0 | 93 | 111 | 133 | 172 | 205 | 257 | 298 | 344 | 361 | 384 | 1.0 | 1.5 | 17 |
| 18 | .749 | 57.5 | .182 | 6.7 | 78.6 | 74.8 | 100 | 123 | 143 | 177 | 216 | 265 | 293 | 340 | 363 | 408 | 1.0 | 1.5 | 18 |
| Average | 0.741 | 59.5 | 0.107 | 8.3 | 81.5 | 75.3 | 96 | 113 | 132 | 164 | 195 | 248 | 292 | 346 | 367 | 396 | 1.0 | 1.6 | Average |

TABLE 1.-Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

South Rocky Mountain area: Arizona, New Mexico, and El Paso, Tex.

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | | Percent | | Item | |
|---------|-------------------------|--------|--------------------|----------------|---------------|------|--------|--------------------|-----|-----|-----|-----|-----|-----|--------------|---------|------|------|---------|
| | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Percent evaporated | | | | | | | End point | Residue | Loss | | |
| | | | | | | | | | | | | | | | | | | | |
| | Sp. G. | A.P.I. | Research | A.S.T.M. | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | | | | |
| 1 | 0.742 | 59.2 | - | 8.2 | 73.0 | 70.2 | 100 | 120 | 138 | 166 | 194 | 241 | 288 | 356 | 380 | 410 | 0.8 | 1.2 | 1 |
| 2 | .735 | 61.0 | - | 9.1 | 74.4 | 70.0 | 96 | 112 | 128 | 156 | 184 | 243 | 302 | 374 | 394 | 420 | .5 | 1.6 | 2 |
| 3 | .751 | 57.0 | - | 7.5 | 74.7 | 70.2 | 103 | 127 | 150 | 182 | 213 | 264 | 310 | 369 | 390 | 413 | .8 | 1.3 | 3 |
| 4 | .744 | 58.8 | 0.169 | 8.3 | 70.4 | 71.0 | 99 | 120 | 144 | 177 | 206 | 254 | 297 | 358 | 383 | 420 | .9 | 1.7 | 4 |
| 5 | .741 | 59.5 | - | 7.5 | 70.5 | 70.0 | 99 | 127 | 146 | 178 | 207 | 253 | 290 | 344 | 370 | 406 | .8 | 1.2 | 5 |
| 6 | .747 | 57.9 | - | 8.0 | 76.2 | 70.9 | 99 | 125 | 139 | 167 | 195 | 251 | 301 | 360 | 381 | 411 | .9 | 1.6 | 6 |
| 7 | .742 | 59.1 | - | 8.5 | 74.8 | 71.6 | 97 | 122 | 143 | 175 | 204 | 250 | 292 | 348 | 375 | 405 | .8 | 1.4 | 7 |
| 8 | .746 | 58.3 | .157 | 7.6 | 71.4 | 71.3 | 102 | 127 | 147 | 180 | 209 | 256 | 299 | 356 | 381 | 414 | .9 | 1.7 | 8 |
| 9 | .741 | 59.5 | - | 9.7 | 75.4 | 70.6 | 90 | 105 | 125 | 158 | 195 | 255 | 308 | 374 | 395 | 423 | .8 | 2.2 | 9 |
| 10 | .750 | 57.3 | - | 7.9 | 74.1 | 69.9 | 96 | 121 | 146 | 179 | 210 | 258 | 304 | 360 | 380 | 410 | .7 | 1.8 | 10 |
| 11 | .748 | 57.6 | - | 8.5 | 76.4 | 70.2 | 96 | 115 | 139 | 173 | 205 | 259 | 305 | 364 | 385 | 407 | .8 | 2.1 | 11 |
| 12 | .752 | 56.7 | - | 7.4 | 74.2 | 69.6 | 101 | 127 | 151 | 186 | 213 | 263 | 307 | 361 | 382 | 411 | .6 | 1.6 | 12 |
| 13 | .753 | 56.5 | - | 7.5 | 74.6 | 70.0 | 102 | 126 | 150 | 186 | 216 | 267 | 313 | 366 | 385 | 411 | .7 | 1.5 | 13 |
| Average | 0.746 | 58.3 | - | 8.1 | 73.9 | 70.4 | 98 | 121 | 142 | 174 | 204 | 255 | 301 | 361 | 383 | 412 | 0.8 | 1.6 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 14 | 0.734 | 61.4 | 0.137 | 9.5 | - | 75.5 | 93 | 103 | 122 | 148 | 174 | 227 | 290 | 368 | 391 | 415 | 1.0 | 2.0 | 14 |
| 15 | .743 | 58.9 | - | 7.1 | 79.8 | 75.8 | 101 | 124 | 145 | 179 | 208 | 252 | 287 | 338 | 359 | 389 | .6 | 1.4 | 15 |
| 16 | .743 | 59.0 | .088 | 6.9 | 75.2 | 73.1 | 105 | 129 | 151 | 182 | 209 | 252 | 292 | 344 | 368 | 407 | 1.0 | 1.3 | 16 |
| 17 | .729 | 62.5 | - | 10.2 | 81.2 | 74.7 | 92 | 106 | 118 | 141 | 167 | 221 | 285 | 365 | 390 | 411 | .7 | 1.5 | 17 |
| Average | 0.737 | 60.5 | 0.113 | 8.4 | 78.7 | 74.8 | 98 | 116 | 134 | 163 | 190 | 238 | 289 | 354 | 377 | 406 | 0.8 | 1.6 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | | | |
|----|-------|------|---|-----|---|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 18 | 0.750 | 57.2 | - | 5.6 | - | 50.0 | 113 | 145 | 166 | 199 | 224 | 268 | 310 | 362 | 387 | 417 | 0.7 | 1.3 | 18 |
| 19 | .747 | 58.0 | - | 7.2 | - | 54.4 | 101 | 127 | 150 | 182 | 211 | 254 | 296 | 357 | 385 | 419 | .7 | 1.5 | 19 |
| 20 | .735 | 61.1 | - | 8.3 | - | 59.2 | 99 | 115 | 128 | 149 | 174 | 233 | 301 | 356 | 375 | 403 | .8 | 1.2 | 20 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)
Middle Rocky Mountain area: includes Amarillo, Tex.; Denver, Colo.; and Salt Lake City, Utah

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | Percent | | Item | |
|---------|-------------------------|------|-----------------|------------|---------------|------|--------|--------------------|-----|-----|-----|-----|-----|-----|-----------|---------|------|---------|
| | Gravity | | Sulfur, percent | R.V.P. lb. | Octane number | | I.B.P. | Percent evaporated | | | | | | | End point | Residue | | Loss |
| | | | | | | | | Percent evaporated | | | | | | | | | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | | | | |
| 1 | 0.731 | 62.0 | - | 9.3 | 73.6 | 70.2 | 91 | 112 | 133 | 163 | 190 | 239 | 291 | 357 | 382 | 0.5 | 1.9 | 1 |
| 2 | .730 | 62.3 | - | 9.2 | 71.8 | 69.6 | 93 | 112 | 135 | 167 | 196 | 247 | 297 | 361 | 383 | 1.0 | 2.0 | 2 |
| 3 | .734 | 61.4 | - | 8.7 | 71.6 | 69.3 | 96 | 115 | 136 | 168 | 197 | 249 | 298 | 360 | 384 | .5 | 2.0 | 3 |
| 4 | .739 | 60.0 | 0.049 | 8.9 | 73.4 | 69.6 | 103 | 121 | 143 | 177 | 208 | 261 | 303 | 357 | 378 | .8 | 1.9 | 4 |
| 5 | .731 | 61.9 | - | 8.8 | 72.0 | 69.5 | 93 | 111 | 127 | 159 | 187 | 241 | 293 | 355 | 378 | .6 | 1.5 | 5 |
| 6 | .735 | 61.0 | - | 10.2 | 71.4 | 70.1 | 92 | 104 | 140 | 178 | 208 | 255 | 301 | 356 | 373 | .6 | 3.4 | 6 |
| 7 | .734 | 61.3 | .028 | 9.0 | 71.8 | 69.9 | 104 | 119 | 139 | 170 | 199 | 250 | 299 | 362 | 385 | .9 | 2.4 | 7 |
| 8 | .735 | 61.4 | - | 9.5 | 72.3 | 69.8 | 93 | 110 | 139 | 177 | 205 | 255 | 304 | 363 | 386 | .3 | 2.8 | 8 |
| 9 | .735 | 61.1 | - | 10.0 | 72.8 | 70.3 | 93 | 105 | 138 | 179 | 209 | 255 | 303 | 360 | 378 | .6 | 3.4 | 9 |
| 10 | .727 | 63.2 | - | 8.2 | 70.4 | 70.4 | 97 | 124 | 152 | 185 | 210 | 250 | 286 | 334 | 354 | .8 | 2.1 | 10 |
| 11 | .735 | 61.0 | - | 8.1 | 71.2 | 69.4 | 99 | 123 | 144 | 175 | 203 | 253 | 304 | 366 | 388 | .4 | 1.6 | 11 |
| 12 | .749 | 57.4 | .044 | 8.9 | 74.0 | 70.0 | 96 | 115 | 139 | 176 | 208 | 266 | 328 | 399 | 421 | 1.1 | 2.9 | 12 |
| 13 | .725 | 63.7 | - | - | 69.7 | 69.3 | - | - | - | - | - | - | - | - | - | - | - | 13 |
| 14 | .730 | 62.3 | - | - | 71.3 | 69.6 | - | - | - | - | - | - | - | - | - | - | - | 14 |
| 15 | .735 | 61.0 | .032 | 7.8 | 73.0 | 70.4 | 97 | 124 | 146 | 176 | 203 | 247 | 291 | 348 | 373 | 1.0 | 1.8 | 15 |
| Average | 0.734 | 61.4 | 0.038 | 9.0 | 72.0 | 69.8 | 96 | 115 | 139 | 173 | 202 | 251 | 300 | 360 | 382 | 0.7 | 2.3 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 16 | 0.734 | 61.2 | - | 9.0 | 81.7 | 75.3 | 93 | 112 | 128 | 152 | 176 | 229 | 283 | 354 | 378 | 0.7 | 1.5 | 16 |
| 17 | .740 | 59.7 | - | 10.0 | 81.4 | 75.2 | 93 | 105 | 122 | 151 | 180 | 246 | 304 | 354 | 377 | .8 | 2.1 | 17 |
| 18 | .733 | 61.5 | - | 8.3 | 81.0 | 76.2 | 97 | 119 | 139 | 164 | 187 | 231 | 272 | 328 | 352 | .9 | 1.3 | 18 |
| 19 | .738 | 60.3 | - | 8.9 | 79.3 | 74.8 | 93 | 112 | 133 | 171 | 203 | 260 | 302 | 355 | 377 | .8 | 2.3 | 19 |
| 20 | .748 | 57.8 | - | 7.6 | 81.2 | 75.5 | 101 | 127 | 145 | 175 | 203 | 252 | 299 | 360 | 384 | .6 | 1.4 | 20 |
| 21 | .737 | 60.5 | - | - | 80.4 | 75.0 | - | - | - | - | - | - | - | - | - | - | - | 21 |
| 22 | .744 | 58.8 | 0.046 | 9.9 | 76.8 | 71.8 | 90 | 106 | 130 | 167 | 202 | 258 | 313 | 390 | 410 | .9 | 3.9 | 22 |
| 23 | .724 | 63.9 | - | - | 80.0 | 75.8 | - | - | - | - | - | - | - | - | - | - | - | 23 |
| 24 | .721 | 64.9 | - | - | 75.3 | 73.6 | - | - | - | - | - | - | - | - | - | - | - | 24 |
| 25 | .730 | 62.3 | - | - | 73.4 | 72.6 | - | - | - | - | - | - | - | - | - | - | - | 25 |
| Average | 0.735 | 61.1 | - | 9.0 | 79.1 | 74.6 | 95 | 114 | 133 | 163 | 192 | 246 | 296 | 357 | 380 | 0.8 | 2.1 | Average |

Third-grade gasoline

| | | | | | | | | | | | | | | | | | | |
|----|-------|------|---|-----|---|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 26 | 0.730 | 62.3 | - | 7.0 | - | 51.1 | 103 | 128 | 145 | 170 | 193 | 248 | 306 | 357 | 380 | 0.6 | 1.1 | 26 |
| 27 | .732 | 61.8 | - | 8.2 | - | 49.9 | 97 | 120 | 148 | 184 | 212 | 257 | 303 | 365 | 390 | .6 | 2.3 | 27 |
| 28 | .736 | 60.8 | - | 7.1 | - | 49.0 | 102 | 129 | 155 | 188 | 215 | 260 | 306 | 366 | 391 | .7 | 1.3 | 28 |
| 29 | .731 | 62.0 | - | 8.3 | - | 49.4 | 93 | 118 | 145 | 177 | 207 | 255 | 302 | 363 | 387 | .8 | 2.2 | 29 |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

North Rocky Mountain area: includes Casper, Wyo.; Pocatello, Idaho; and cities in Montana

Regular-price gasoline

| Item | Distillation range, °F. | | | | | | | | | | | | | | | | | Item | |
|---------|-------------------------|--------|--------------------|----------------|---------------|----------|--------|--------------------|-----|-----|-----|-----|-----|-----|--------------|---------|---------|------|---------|
| | Gravity Specific | A.P.I. | Sulfur, percent | R.V.P., lb. | Octane number | | I.B.P. | Percent evaporated | | | | | | | End point | Percent | | | |
| | | | | | Research | A.S.T.M. | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | | 95 | Residue | | Loss |
| | | | | | | | | | | | | | | | | | | | |
| 1 | 0.737 | 60.6 | 0.039 | 8.8 | 73.2 | 69.8 | 98 | 110 | 129 | 165 | 200 | 255 | 300 | 355 | 375 | 402 | 1.0 | 1.6 | 1 |
| 2 | .732 | 61.7 | - | - | 72.2 | 70.4 | - | - | - | - | - | - | - | - | - | 396 | - | - | 2 |
| 3 | .731 | 62.0 | .059 | 9.9 | 73.6 | 69.8 | 100 | 115 | 130 | 157 | 183 | 232 | 279 | 335 | 360 | 408 | 1.0 | 2.2 | 3 |
| 4 | .740 | 59.7 | .096 | 9.6 | 74.9 | 70.6 | 99 | 111 | 128 | 160 | 190 | 241 | 289 | 350 | 371 | 408 | 1.0 | 1.8 | 4 |
| 5 | .739 | 59.9 | .102 | 8.0 | 74.3 | 69.9 | 105 | 119 | 133 | 161 | 187 | 237 | 279 | 336 | 369 | 383 | 1.0 | 1.7 | 5 |
| 6 | .752 | 56.7 | .185 | 10.2 | 76.1 | 69.7 | 97 | 119 | 145 | 179 | 208 | 262 | 313 | 377 | 400 | 430 | 1.0 | 2.8 | 6 |
| 7 | .741 | 59.4 | .178 | 8.7 | 73.0 | 71.0 | 91 | 105 | 126 | 162 | 199 | 259 | 306 | 361 | 381 | 400 | 1.0 | 2.0 | 7 |
| 8 | .731 | 62.0 | .061 | 8.3 | 69.0 | 69.0 | 105 | 129 | 149 | 180 | 208 | 258 | 300 | 347 | 363 | 386 | 1.0 | 1.0 | 8 |
| 9 | .724 | 64.0 | - | - | 73.9 | 69.9 | - | - | - | - | - | - | - | - | - | - | - | - | 9 |
| 10 | .734 | 61.2 | .088 | 8.6 | 74.7 | 70.7 | 97 | 118 | 139 | 169 | 199 | 251 | 299 | 357 | 377 | 410 | 1.0 | 1.7 | 10 |
| 11 | .739 | 60.0 | .120 | 7.1 | 74.4 | 69.4 | 101 | 127 | 145 | 173 | 201 | 251 | 293 | 345 | 363 | 385 | 1.0 | .8 | 11 |
| 12 | .730 | 62.4 | .015 | 10.3 | 72.2 | 72.0 | 100 | 115 | 135 | 162 | 187 | 228 | 272 | 341 | 370 | 398 | 1.0 | 2.2 | 12 |
| Average | 0.736 | 60.8 | 0.094 | 9.0 | 73.5 | 70.2 | 99 | 117 | 136 | 167 | 196 | 247 | 293 | 350 | 373 | 400 | 1.0 | 1.8 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 13 | 0.741 | 59.5 | 0.053 | 9.1 | 82.4 | 74.8 | 95 | 114 | 134 | 167 | 200 | 255 | 301 | 355 | 378 | 1.0 | 2.0 | 13 |
| 14 | .729 | 62.5 | - | - | 79.1 | 74.6 | - | - | - | - | - | - | - | - | - | - | - | 14 |
| 15 | .738 | 60.3 | .080 | 8.8 | 82.7 | 75.6 | 103 | 120 | 137 | 164 | 189 | 235 | 280 | 343 | 362 | 1.0 | 1.4 | 15 |
| 16 | .746 | 58.3 | .147 | 11.6 | 82.9 | 75.6 | 89 | 104 | 131 | 168 | 198 | 249 | 297 | 357 | 380 | .9 | 3.7 | 16 |
| 17 | .746 | 58.3 | .117 | 7.9 | 81.3 | 74.8 | 107 | 127 | 143 | 169 | 197 | 256 | 309 | 371 | 386 | 1.0 | .8 | 17 |
| 18 | .732 | 61.7 | - | - | 81.7 | 75.2 | - | - | - | - | - | - | - | - | - | - | - | 18 |
| 19 | .741 | 59.6 | .077 | 9.0 | 83.8 | 75.7 | 101 | 115 | 131 | 160 | 188 | 243 | 293 | 355 | 379 | 1.0 | 2.0 | 19 |
| 20 | .744 | 58.6 | .141 | 7.8 | 82.3 | 74.7 | 108 | 124 | 145 | 175 | 205 | 257 | 300 | 349 | 366 | 1.0 | 1.3 | 20 |
| 21 | .734 | 61.3 | .019 | 8.3 | 78.1 | 76.0 | 97 | 121 | 144 | 171 | 193 | 234 | 278 | 342 | 370 | 1.0 | 1.0 | 21 |
| 22 | .731 | 62.2 | .102 | 9.6 | 81.2 | 75.3 | 105 | 115 | 126 | 150 | 177 | 233 | 287 | 348 | 367 | 1.0 | 1.1 | 22 |
| 23 | .732 | 61.9 | - | - | 76.9 | 73.6 | - | - | - | - | - | - | - | - | - | - | - | 23 |
| 24 | .741 | 59.6 | - | - | 82.9 | 75.7 | - | - | - | - | - | - | - | - | - | - | - | 24 |
| Average | 0.738 | 60.3 | 0.092 | 9.0 | 81.3 | 75.1 | 101 | 118 | 136 | 166 | 193 | 245 | 293 | 353 | 374 | 1.0 | 1.7 | Average |

TABLE 1.- Motor-gasoline survey, winter 1941-45
(Data for samples from different districts)

Seattle, Wash.

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | Distillation range, °F. | | | | | | | | | | | Percent | | item |
|---------|----------|--------|--------------------|----------------|---------------|----------|-------------------------|--------------------|-----|-----|-----|-----|-----|-----|-----|--------------|---------|---------|--|------|
| | Specific | A.P.I. | | | Research | A.S.T.M. | I.B.P. | Percent evaporated | | | | | | | | End point | Residue | Loss | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | 95 | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| A | 0.748 | 57.6 | 0.08 | 7.5 | 74.8 | 71.2 | 99 | 128 | 146 | 181 | 215 | 261 | 299 | 343 | 366 | 1.0 | 1.0 | 1 | | |
| B | .750 | 57.3 | .12 | 8.4 | 71.5 | 70.4 | 92 | 114 | 138 | 179 | 215 | 269 | 307 | 356 | 377 | 1.0 | 2.0 | 2 | | |
| C | .760 | 54.8 | .18 | 7.3 | 74.6 | 71.2 | 104 | 137 | 163 | 204 | 233 | 273 | 304 | 346 | 364 | 1.0 | 1.0 | 3 | | |
| D | .759 | 54.9 | .11 | 7.9 | 75.4 | 71.3 | 107 | 135 | 163 | 202 | 230 | 266 | 298 | 343 | 365 | 1.0 | 1.5 | 4 | | |
| E | .753 | 56.4 | .20 | 7.4 | 75.5 | 72.1 | 93 | 115 | 143 | 179 | 208 | 256 | 296 | 348 | 371 | 1.0 | 2.0 | 5 | | |
| F | .755 | 55.9 | .16 | 7.4 | 73.8 | 70.3 | 94 | 121 | 143 | 183 | 225 | 271 | 303 | 345 | 363 | 1.0 | 1.5 | 6 | | |
| G | .760 | 54.6 | .20 | 8.7 | 76.6 | 71.2 | 90 | 113 | 138 | 175 | 211 | 262 | 300 | 346 | 372 | 1.0 | 2.0 | 7 | | |
| Average | 0.755 | 55.9 | 0.15 | 7.8 | 74.6 | 71.1 | 97 | 123 | 148 | 186 | 220 | 265 | 301 | 347 | 368 | 1.0 | 1.6 | Average | | |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| A | 0.747 | 58.0 | 0.13 | 7.6 | 80.1 | 76.5 | 95 | 115 | 136 | 167 | 200 | 258 | 296 | 348 | 368 | 1.0 | 2.0 | 8 |
| B | .750 | 57.2 | .14 | 8.4 | 74.4 | 74.1 | 97 | 116 | 139 | 175 | 211 | 256 | 302 | 352 | 374 | 1.0 | 2.0 | 9 |
| C | .745 | 58.4 | .12 | 8.0 | 81.4 | 77.0 | 99 | 117 | 137 | 167 | 201 | 255 | 291 | 338 | 358 | 1.0 | 2.0 | 10 |
| D | .757 | 55.4 | .20 | 8.2 | 81.8 | 77.0 | 108 | 138 | 164 | 196 | 220 | 257 | 299 | 355 | 382 | 1.0 | 1.5 | 11 |
| E | .759 | 54.9 | .15 | 7.3 | 83.6 | 77.0 | 108 | 126 | 146 | 177 | 204 | 257 | 299 | 352 | 378 | 1.0 | 1.0 | 12 |
| F | .747 | 58.0 | .13 | 5.7 | 81.0 | 76.8 | 99 | 123 | 143 | 173 | 206 | 262 | 295 | 341 | 377 | 1.0 | 1.0 | 13 |
| G | .746 | 58.3 | .18 | 8.4 | 81.0 | 77.1 | 91 | 110 | 132 | 150 | 183 | 239 | 285 | 347 | 370 | 1.0 | 2.0 | 14 |
| Average | 0.750 | 57.2 | 0.15 | 7.7 | 80.5 | 76.5 | 100 | 121 | 142 | 172 | 204 | 255 | 295 | 348 | 372 | 1.0 | 1.6 | Average |

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number Research | A.S.T.M. | I.B.P. | Distillation range, °F. | | | | | | | Percent | | Item | | |
|---------|----------|---------|--------------------|----------------|---------------------------|----------|--------|-------------------------|-----|-----|-----|-----|-----|-----|---------|------|------|-----|--------------|
| | Specific | °A.P.I. | | | | | | Percent evaporated | | | | | | | Residue | Loss | | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | 90 | | | | 95 | End point |
| 1 | 0.756 | 55.8 | 0.152 | 7.0 | 75.1 | 70.8 | 99 | 118 | 142 | 185 | 220 | 265 | 300 | 349 | - | 401 | 0.6 | 2.4 | 1 |
| 2 | .759 | 55.0 | .137 | 6.8 | - | 69.5 | 104 | 123 | 146 | 192 | 228 | 277 | 312 | 351 | - | 396 | .7 | 1.3 | 2 |
| 3 | .754 | 56.3 | .108 | 7.9 | 73.4 | 70.0 | 97 | 118 | 143 | 189 | 225 | 269 | 300 | 350 | - | 394 | .7 | 1.8 | 3 |
| 4 | .756 | 55.7 | .115 | 7.7 | - | 69.6 | 99 | 118 | 147 | 196 | 233 | 276 | 310 | 358 | - | 400 | .6 | 2.3 | 4 |
| 5 | .753 | 56.5 | .150 | 7.0 | - | 69.0 | 100 | 118 | 140 | 179 | 210 | 268 | 303 | 350 | - | 400 | .7 | 1.8 | 5 |
| 6 | .756 | 55.8 | .161 | 6.9 | 76.0 | 69.9 | 100 | 118 | 142 | 178 | 212 | 261 | 298 | 347 | - | 394 | .5 | 2.0 | 6 |
| 7 | .760 | 54.8 | .158 | 8.5 | - | 68.6 | 96 | 105 | 131 | 183 | 230 | 279 | 315 | 359 | - | 396 | .5 | 3.2 | 7 |
| 8 | .757 | 55.5 | .248 | 7.0 | - | 70.0 | 102 | 127 | 152 | 192 | 225 | 270 | 305 | 350 | - | 400 | .7 | 2.0 | 8 |
| 9 | .759 | 55.0 | .186 | 7.6 | 77.0 | 70.6 | 99 | 127 | 156 | 196 | 226 | 266 | 294 | 335 | - | 397 | .7 | 2.3 | 9 |
| 10 | .755 | 56.0 | .242 | 7.6 | 77.8 | 70.8 | 103 | 120 | 145 | 183 | 216 | 261 | 295 | 342 | - | 400 | .6 | 1.9 | 10 |
| 11 | .760 | 54.6 | .152 | 8.0 | 73.5 | 70.0 | 98 | 116 | 146 | 209 | 248 | 278 | 300 | 338 | - | 384 | .7 | 2.4 | 11 |
| 12 | .755 | 55.9 | .297 | 8.6 | 76.6 | 71.0 | 95 | 118 | 140 | 175 | 211 | 257 | 294 | 340 | - | 387 | .5 | 2.5 | 12 |
| 13 | .758 | 55.2 | .285 | 7.2 | - | 70.0 | 102 | 124 | 146 | 186 | 216 | 262 | 300 | 350 | - | 403 | .5 | 2.0 | 13 |
| Average | 0.757 | 55.5 | 0.184 | 7.5 | 75.6 | 70.0 | 100 | 119 | 144 | 188 | 223 | 268 | 302 | 348 | - | 396 | 0.6 | 2.1 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|---|-----|-----|---------|
| 14 | 0.758 | 55.3 | 0.152 | 7.0 | 80.7 | 75.3 | 102 | 126 | 150 | 190 | 223 | 270 | 309 | 358 | - | 403 | 0.6 | 14 |
| 15 | .756 | 55.7 | .116 | 7.1 | - | 75.0 | 99 | 122 | 148 | 185 | 220 | 268 | 308 | 348 | - | 389 | .7 | 15 |
| 16 | .755 | 56.0 | .133 | 7.7 | 80.6 | 75.6 | 98 | 120 | 148 | 192 | 230 | 270 | 302 | 350 | - | 398 | .7 | 16 |
| 17 | .757 | 55.5 | .120 | 7.7 | - | 75.0 | 99 | 125 | 150 | 199 | 231 | 275 | 310 | 354 | - | 398 | .7 | 17 |
| 18 | .746 | 58.1 | .151 | 7.0 | - | 75.6 | 98 | 115 | 135 | 170 | 202 | 252 | 291 | 345 | - | 395 | .6 | 18 |
| 19 | .749 | 57.4 | .164 | 6.8 | 81.7 | 75.2 | 99 | 117 | 139 | 174 | 205 | 258 | 297 | 348 | - | 397 | .7 | 19 |
| 20 | .759 | 55.0 | .202 | 8.5 | - | 74.6 | 96 | 111 | 138 | 180 | 224 | 274 | 311 | 365 | - | 400 | .5 | 20 |
| 21 | .760 | 54.8 | .211 | 6.6 | - | 75.0 | 101 | 122 | 150 | 196 | 232 | 272 | 308 | 352 | - | 402 | .8 | 21 |
| 22 | .752 | 56.8 | .170 | 8.2 | 83.4 | 75.6 | 98 | 118 | 143 | 178 | 205 | 250 | 290 | 340 | - | 393 | .5 | 22 |
| 23 | .754 | 56.3 | .201 | 7.7 | 84.0 | 76.2 | 98 | 115 | 135 | 171 | 200 | 250 | 291 | 340 | - | 393 | .6 | 23 |
| 24 | .752 | 56.7 | .171 | 7.1 | 77.8 | 75.3 | 96 | 118 | 138 | 180 | 225 | 268 | 294 | 331 | - | 378 | .8 | 24 |
| 25 | .752 | 56.7 | .322 | 8.1 | 82.0 | 75.7 | 99 | 117 | 138 | 170 | 199 | 248 | 285 | 335 | - | 383 | .5 | 25 |
| 26 | .754 | 56.2 | .302 | 7.4 | - | 74.0 | 100 | 117 | 138 | 173 | 206 | 257 | 300 | 350 | - | 401 | .7 | 26 |
| Average | 0.754 | 56.2 | 0.186 | 7.5 | 81.5 | 75.2 | 99 | 119 | 142 | 181 | 216 | 262 | 300 | 347 | - | 395 | 0.6 | Average |

San Francisco Bay region, Calif.

TABLE 1.- Motor-gasoline survey, winter 1944-45
(Data for samples from different districts)

Regular-price gasoline

| Item | Gravity | | Sulfur, percent | R.V.P., lb. | Octane number | | Distillation range, °F. | | | | | | | | | | Percent | | Item |
|---------|----------|---------|--------------------|----------------|---------------|----------|-------------------------|-----|-----|-----|-----|-----|-----|--------------|---------|------|---------|-----|---------|
| | Specific | °A.P.I. | | | Research | A.S.T.M. | Percent evaporated | | | | | | | End point | Residue | Loss | | | |
| | | | | | | | I.B.P. | 5 | 10 | 20 | 30 | 50 | 70 | | | | 90 | 95 | |
| | | | | | | | | | | | | | | | | | | | |
| A | 0.755 | 56.0 | 0.18 | 8.4 | - | 71.5 | 98 | 112 | 147 | 182 | 212 | 264 | 302 | 351 | 376 | 402 | 1.0 | 1.0 | 1 |
| B | .745 | 58.4 | .56 | 10.7 | - | 70.0 | 93 | 99 | 132 | 158 | 195 | 254 | 294 | 358 | 376 | 421 | 1.0 | 4.0 | 2 |
| C | .741 | 59.6 | .55 | 10.0 | - | 70.0 | 91 | 98 | 126 | 150 | 183 | 249 | 296 | 354 | 385 | 400 | 1.0 | 3.5 | 3 |
| D | .763 | 54.1 | .086 | 6.8 | - | 70.0 | 102 | 129 | 158 | 189 | 214 | 259 | 302 | 370 | 392 | 420 | 1.0 | 1.5 | 4 |
| E | .758 | 55.3 | .13 | 6.7 | - | 70.0 | 106 | 135 | 157 | 191 | 219 | 261 | 306 | 360 | 383 | 416 | 1.0 | 3.0 | 5 |
| F | .760 | 54.7 | .10 | 7.0 | - | 70.0 | 91 | 117 | 146 | 201 | 247 | 283 | 310 | 345 | 367 | 392 | 1.0 | 1.5 | 6 |
| G | .760 | 54.6 | .095 | 5.7 | - | 70.0 | 110 | 137 | 163 | 192 | 219 | 268 | 310 | 365 | 386 | 414 | 1.0 | 1.0 | 7 |
| Average | 0.754 | 56.1 | 0.243 | 7.9 | - | 70.2 | 99 | 118 | 147 | 180 | 213 | 263 | 303 | 358 | 381 | 409 | 1.0 | 2.2 | Average |

Premium-price gasoline

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|------|-------|-----|---|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| A | 0.750 | 57.1 | 0.091 | 8.0 | - | 76.0 | 97 | 118 | 145 | 174 | 204 | 249 | 287 | 362 | 389 | 414 | 1.0 | 1.5 | 8 |
| B | .753 | 56.4 | .12 | 6.0 | - | 74.5 | 100 | 122 | 145 | 176 | 205 | 252 | 295 | 350 | 371 | 407 | 1.0 | 1.0 | 9 |
| C | .749 | 57.5 | .42 | 9.0 | - | 74.5 | 93 | 103 | 133 | 164 | 195 | 252 | 295 | 355 | 385 | 403 | 1.0 | 3.0 | 10 |
| D | .762 | 54.2 | .17 | 7.0 | - | 74.5 | 90 | 113 | 151 | 211 | 253 | 283 | 310 | 346 | 363 | 396 | 1.0 | 2.0 | 11 |
| E | .746 | 58.1 | .37 | 8.0 | - | 75.5 | 90 | 111 | 132 | 164 | 196 | 251 | 300 | 356 | 382 | 406 | 1.0 | 1.5 | 12 |
| F | .754 | 56.3 | .15 | 8.0 | - | 76.0 | 93 | 108 | 125 | 156 | 186 | 245 | 298 | 355 | 380 | 410 | 1.0 | 1.5 | 13 |
| G | .756 | 55.8 | .11 | 5.9 | - | 74.5 | 102 | 126 | 147 | 178 | 208 | 254 | 297 | 360 | 378 | 412 | 1.0 | 1.0 | 14 |
| Average | 0.753 | 56.5 | 0.20 | 7.4 | - | 75.1 | 95 | 114 | 140 | 175 | 207 | 255 | 297 | 355 | 378 | 407 | 1.0 | 1.6 | Average |

TABLE 2.- Motor-gasoline survey, winter 1944-45
(Average values for samples from different districts)

Regular-price gasoline

| District | Distillation range, °F. | | | | | | | | | | | | | | District | | | |
|-----------------|-------------------------|--------|----------------|-------------|---------------|----------|--------------------|-----|-----|-----|-----|-----|-----|---------|----------|-----------|-----|-----------------|
| | Gravity | | Sulfur percent | R.V.P., lb. | Octane number | | Percent evaporated | | | | | | | Percent | | | | |
| | | | | | | | I.B.P. | | | | | | | | | End point | | |
| | | | | | | | | 5 | 10 | 20 | 30 | 50 | 70 | | | | 90 | 95 |
| | Specific | A.P.I. | | | Research | A.S.T.M. | | | | | | | | | | | | |
| Boston | 0.737 | 60.5 | 0.112 | 9.6 | 73.9 | 69.7 | 91 | 110 | 130 | 158 | 185 | 236 | 282 | 346 | 371 | 1.1 | 1.9 | Boston |
| New York | .740 | 59.8 | .056 | 9.7 | 74.6 | 70.5 | 92 | 108 | 128 | 159 | 189 | 243 | 286 | 344 | 370 | 1.0 | 2.3 | New York |
| Wash., D. C. | .738 | 60.2 | .066 | 10.6 | 73.8 | 70.0 | 88 | 102 | 122 | 156 | 190 | 244 | 288 | 343 | 366 | 1.1 | 2.6 | Wash., D.C. |
| Pittsburgh | .733 | 61.5 | .082 | 10.4 | 75.1 | 70.6 | 91 | 107 | 127 | 157 | 188 | 242 | 285 | 339 | 363 | .9 | 2.7 | Pittsburgh |
| Cleveland | .736 | 60.8 | .067 | 9.8 | 74.5 | 70.1 | 92 | 110 | 127 | 155 | 183 | 237 | 287 | 352 | 380 | 1.2 | 1.8 | Cleveland |
| Detroit | .728 | 63.0 | .083 | 10.4 | 72.9 | 69.9 | 88 | 105 | 123 | 151 | 177 | 229 | 274 | 338 | 367 | 1.1 | 2.2 | Detroit |
| Atlanta | .747 | 57.9 | .066 | 8.3 | 74.8 | 69.9 | 97 | 116 | 137 | 168 | 198 | 248 | 294 | 351 | 374 | 1.0 | 2.1 | Atlanta |
| Chicago | .731 | 62.1 | .061 | 10.8 | 73.2 | 70.2 | 90 | 102 | 121 | 150 | 181 | 238 | 287 | 347 | 371 | .7 | 2.8 | Chicago |
| New Orleans | .746 | 58.3 | .059 | 8.2 | 74.3 | 70.1 | 95 | 116 | 136 | 168 | 197 | 245 | 288 | 348 | 373 | 1.1 | 1.5 | New Orleans |
| Memphis | .748 | 57.8 | .077 | 8.4 | 75.8 | 70.3 | 97 | 115 | 137 | 169 | 201 | 252 | 297 | 351 | 372 | 1.0 | 1.9 | Memphis |
| St. Louis | .735 | 61.1 | .062 | 9.8 | 73.9 | 69.8 | 93 | 108 | 127 | 158 | 188 | 240 | 286 | 343 | 366 | .8 | 2.5 | St. Louis |
| Minneapolis | .729 | 62.6 | .065 | 9.8 | 73.4 | 70.4 | 93 | 109 | 126 | 152 | 178 | 232 | 282 | 343 | 368 | .8 | 2.0 | Minneapolis |
| Omaha | .729 | 62.7 | .066 | 10.0 | 73.2 | 70.1 | 96 | 115 | 132 | 156 | 178 | 225 | 275 | 340 | 368 | .9 | 2.1 | Omaha |
| Tulsa | .730 | 62.3 | .050 | 9.9 | 73.2 | 69.6 | 94 | 110 | 127 | 155 | 182 | 234 | 283 | 343 | 369 | .9 | 2.3 | Tulsa |
| Texas | .744 | 58.6 | .128 | 8.1 | 77.2 | 70.5 | 98 | 117 | 135 | 166 | 196 | 252 | 297 | 352 | 373 | 1.0 | 1.4 | Texas |
| S. Rocky. Mt. | .745 | 58.3 | - | 8.1 | 73.9 | 70.4 | 98 | 121 | 142 | 174 | 204 | 255 | 301 | 361 | 383 | .8 | 1.6 | S. Rocky. Mt. |
| Mid. Rocky. Mt. | .734 | 61.4 | .038 | 9.0 | 72.0 | 69.8 | 96 | 115 | 139 | 173 | 202 | 251 | 300 | 360 | 382 | .7 | 2.3 | Mid. Rocky. Mt. |
| N. Rocky. Mt. | .736 | 60.8 | .094 | 9.0 | 73.5 | 70.2 | 99 | 117 | 136 | 167 | 196 | 247 | 293 | 350 | 373 | 1.0 | 1.8 | N. Rocky. Mt. |
| Seattle | .755 | 55.9 | .15 | 7.8 | 74.6 | 71.1 | 97 | 123 | 148 | 186 | 220 | 265 | 301 | 347 | 368 | 1.0 | 1.6 | Seattle |
| Los Angeles | .757 | 55.5 | .184 | 7.5 | 75.6 | 70.0 | 100 | 119 | 144 | 188 | 223 | 268 | 302 | 348 | - | .6 | 2.1 | Los Angeles |
| San Francisco | .754 | 56.1 | .243 | 7.9 | - | 70.2 | 99 | 118 | 147 | 180 | 213 | 263 | 303 | 358 | 381 | 1.0 | 2.2 | San Francisco |
| Average | 0.739 | 59.9 | 0.092 | 9.2 | 74.2 | 70.2 | 94 | 113 | 133 | 164 | 194 | 245 | 290 | 348 | 372 | 0.9 | 2.1 | Average |

TABLE 3.- Motor-gasoline survey, winter 1944-45
(Average values for samples from different districts)

Premium-price gasoline

| District | Distillation range, °F. | | | | | | | | | | Percent | | District | | | | | | |
|----------------|-------------------------|--------|----------------|-------------|---------------|----------|--------|--------------------|-----|-----|---------|-----------|----------|---------|------|-----|-----|-----|----------------|
| | Gravity | | Sulfur percent | R.V.P., lb. | Octane number | | I.B.P. | Percent evaporated | | | | End point | | Residue | Loss | | | | |
| | Specific | A.P.I. | | | Research | A.S.T.M. | | 5 | 10 | 20 | 30 | | | | | 50 | 70 | 90 | 95 |
| Boston | 0.741 | 59.6 | 0.168 | 9.8 | 81.1 | 74.9 | 90 | 106 | 125 | 151 | 177 | 227 | 275 | 339 | 365 | 396 | 1.0 | 2.1 | Boston |
| New York | .741 | 59.5 | .066 | 9.4 | 80.1 | 74.9 | 94 | 113 | 132 | 163 | 192 | 242 | 287 | 347 | 372 | 405 | 1.1 | 2.0 | New York |
| Wash., D. C. | .742 | 59.3 | .077 | 9.0 | 82.2 | 75.7 | 94 | 111 | 129 | 158 | 188 | 242 | 292 | 354 | 378 | 405 | 1.0 | 1.9 | Wash., D. C. |
| Pittsburgh | .737 | 60.5 | .087 | 9.7 | 80.1 | 74.6 | 94 | 110 | 129 | 158 | 187 | 240 | 287 | 345 | 370 | 401 | 1.0 | 2.5 | Pittsburgh |
| Cleveland | .735 | 61.1 | .053 | 9.4 | 80.8 | 75.5 | 97 | 117 | 133 | 160 | 186 | 235 | 285 | 351 | 378 | 408 | 1.0 | 1.9 | Cleveland |
| Detroit | .728 | 62.9 | .075 | 10.7 | 78.7 | 74.8 | 87 | 103 | 120 | 146 | 172 | 224 | 274 | 340 | 368 | 403 | 1.1 | 2.4 | Detroit |
| Atlanta | .746 | 58.3 | .082 | 7.9 | 80.8 | 74.0 | 97 | 125 | 144 | 174 | 202 | 249 | 294 | 350 | 372 | 401 | 1.0 | 1.3 | Atlanta |
| Chicago | .733 | 61.6 | .083 | 10.7 | 80.5 | 75.1 | 89 | 103 | 119 | 147 | 177 | 233 | 283 | 346 | 373 | 404 | .9 | 2.4 | Chicago |
| New Orleans | .751 | 56.9 | .054 | 8.1 | 81.5 | 75.1 | 97 | 116 | 137 | 170 | 201 | 253 | 297 | 353 | 376 | 406 | 1.0 | 1.8 | New Orleans |
| Memphis | .753 | 56.4 | .068 | 7.8 | 81.7 | 75.4 | 95 | 118 | 139 | 168 | 205 | 256 | 300 | 353 | 377 | 416 | 1.0 | 1.4 | Memphis |
| St. Louis | .734 | 61.2 | .063 | 9.4 | 80.5 | 75.5 | 95 | 112 | 131 | 160 | 187 | 237 | 284 | 341 | 364 | 393 | .9 | 2.1 | St. Louis |
| Minneapolis | .727 | 63.2 | .072 | 9.7 | 78.7 | 74.9 | 93 | 110 | 126 | 151 | 177 | 229 | 282 | 345 | 371 | 404 | .9 | 1.8 | Minneapolis |
| Omaha | .726 | 63.4 | .054 | 10.6 | 80.2 | 75.4 | 96 | 110 | 125 | 149 | 173 | 223 | 271 | 333 | 359 | 395 | .9 | 2.5 | Omaha |
| Tulsa | .730 | 62.4 | .058 | 9.6 | 80.5 | 75.4 | 97 | 111 | 128 | 154 | 180 | 232 | 280 | 341 | 367 | 397 | .9 | 2.1 | Tulsa |
| Texas | .741 | 59.5 | .107 | 8.3 | 81.5 | 75.3 | 96 | 113 | 132 | 164 | 195 | 248 | 292 | 346 | 367 | 396 | 1.0 | 1.6 | Texas |
| S. Roky. Mt. | .737 | 60.5 | .113 | 8.4 | 78.7 | 74.8 | 98 | 116 | 134 | 163 | 190 | 238 | 289 | 354 | 377 | 406 | .8 | 1.6 | S. Roky. Mt. |
| Mid. Roky. Mt. | .735 | 61.1 | - | 9.0 | 79.1 | 74.6 | 95 | 114 | 133 | 163 | 192 | 246 | 296 | 357 | 380 | 412 | .8 | 2.1 | Mid. Roky. Mt. |
| N. Roky. Mt. | .738 | 60.3 | .092 | 9.0 | 81.3 | 75.1 | 101 | 118 | 136 | 166 | 193 | 245 | 293 | 353 | 374 | 402 | 1.0 | 1.7 | N. Roky. Mt. |
| Seattle | .750 | 57.2 | .15 | 7.7 | 80.5 | 76.5 | 100 | 121 | 142 | 172 | 204 | 255 | 295 | 348 | 372 | 400 | 1.0 | 1.6 | Seattle |
| Los Angeles | .754 | 56.2 | .186 | 7.5 | 81.5 | 75.2 | 99 | 119 | 142 | 181 | 216 | 262 | 300 | 347 | - | 395 | .6 | 1.8 | Los Angeles |
| San Francisco | .753 | 56.5 | .20 | 7.4 | - | 75.1 | 95 | 114 | 140 | 175 | 207 | 255 | 297 | 355 | 378 | 407 | 1.0 | 1.6 | San Francisco |
| Average | 0.739 | 59.9 | 0.095 | 9.0 | 80.5 | 75.1 | 95 | 113 | 132 | 162 | 191 | 241 | 288 | 348 | 372 | 402 | 0.9 | 1.9 | Average |

TABLE 4.- Motor-gasoline survey, winter 1944-45
(Summary of data of the survey)

| Test | Regular-price gasoline | | | Premium-price gasoline | | |
|-----------------------------|------------------------|---------|---------|------------------------|---------|---------|
| | Minimum | Average | Maximum | Minimum | Average | Maximum |
| Gravity, degrees A.P.I. | 54.1 | 59.9 | 66.7 | 54.2 | 59.9 | 68.7 |
| Sulfur content, percent | .015 | .092 | .56 | .016 | .095 | .42 |
| Reid vapor pressure, pounds | 5.1 | 9.2 | 14.1 | 5.7 | 9.0 | 13.7 |
| A.S.T.M. octane number | 66.5 | 70.2 | 72.2 | 69.0 | 75.1 | 77.2 |
| Initial boiling point, °F. | 81 | 94 | 110 | 79 | 95 | 117 |
| 5% evaporated | 92 | 113 | 141 | 88 | 113 | 138 |
| 10% evaporated | 109 | 133 | 163 | 101 | 132 | 164 |
| 20% evaporated | 132 | 164 | 209 | 123 | 162 | 211 |
| 30% evaporated | 154 | 194 | 248 | 146 | 191 | 253 |
| 50% evaporated | 210 | 245 | 283 | 200 | 241 | 283 |
| 70% evaporated | 251 | 290 | 328 | 255 | 288 | 316 |
| 90% evaporated | 299 | 348 | 399 | 310 | 348 | 390 |
| 95% evaporated | 318 | 372 | 421 | 329 | 372 | 413 |
| End point | 345 | 403 | 443 | 364 | 402 | 455 |
| Distillation loss | .8 | 2.1 | 4.5 | .8 | 1.9 | 5.5 |

TABLE 5.- Motor-gasoline survey, winter 1943-44
(Summary of data of the survey)

| Test | Regular-price gasoline | | | Premium-price gasoline | | | Third-grade gasoline | | |
|-----------------------------|------------------------|---------|---------|------------------------|---------|---------|----------------------|---------|---------|
| | Minimum | Average | Maximum | Minimum | Average | Maximum | Minimum | Average | Maximum |
| Gravity, degrees A.P.I. | 52.6 | 60.9 | 73.0 | 52.7 | 60.8 | 68.4 | 54.6 | 61.2 | 66.0 |
| Sulfur content, percent | .012 | .085 | .38 | .016 | .078 | .37 | .02 | .129 | .34 |
| Reid vapor pressure, pounds | 5.1 | 9.4 | 12.6 | 5.5 | 9.6 | 12.6 | 5.6 | 8.5 | 12.0 |
| A.S.T.M. octane number | 60.5 | 71.7 | 75.0 | 71.7 | 75.8 | 79.1 | 44.3 | 60.5 | 75.0 |
| Initial boiling point, °F. | 81 | 93 | 113 | 74 | 91 | 104 | 80 | 96 | 120 |
| 5% evaporated | 91 | 112 | 137 | 90 | 109 | 134 | 100 | 119 | 140 |
| 10% evaporated | 106 | 130 | 167 | 105 | 128 | 160 | 112 | 134 | 164 |
| 20% evaporated | 122 | 162 | 210 | 120 | 158 | 206 | 132 | 165 | 195 |
| 30% evaporated | 138 | 191 | 241 | 135 | 188 | 242 | 154 | 195 | 230 |
| 50% evaporated | 183 | 242 | 284 | 183 | 238 | 284 | 216 | 246 | 283 |
| 70% evaporated | 243 | 287 | 326 | 238 | 283 | 334 | 259 | 290 | 319 |
| 90% evaporated | 293 | 345 | 396 | 292 | 342 | 391 | 322 | 348 | 373 |
| 95% evaporated | 313 | 369 | 419 | 315 | 366 | 411 | 362 | 374 | 400 |
| End point | 352 | 401 | 458 | 360 | 397 | 450 | 378 | 405 | 439 |
| Distillation loss | .0 | 1.9 | 4.5 | .0 | 2.0 | 4.5 | .5 | 1.5 | 3.0 |

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185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 | 225 | 226 | 227 | 228 | 229 | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 | 240 | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 | 253 | 254 | 255 | 256 | 257 | 258 | 259 | 260 | 261 | 262 | 263 | 264 | 265 | 266 | 267 | 268 | 269 | 270 | 271 | 272 | 273 | 274 | 275 | 276 | 277 | 278 | 279 | 280 | 281 | 282 | 283 | 284 | 285 | 286 | 287 | 288 | 289 | 290 | 291 | 292 | 293 | 294 | 295 | 296 | 297 | 298 | 299 | 300 | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 | 309 | 310 | 311 | 312 | 313 | 314 | 315 | 316 | 317 | 318 | 319 | 320 | 321 | 322 | 323 | 324 | 325 | 326 | 327 | 328 | 329 | 330 | 331 | 332 | 333 | 334 | 335 | 336 | 337 | 338 | 339 | 340 | 341 | 342 | 343 | 344 | 345 | 346 | 347 | 348 | 349 | 350 | 351 | 352 | 353 | 354 | 355 | 356 | 357 | 358 | 359 | 360 | 361 | 362 | 363 | 364 | 365 | 366 | 367 | 368 | 369 | 370 | 371 | 372 | 373 | 374 | 375 | 376 | 377 | 378 | 379 | 380 | 381 | 382 | 383 | 384 | 385 | 386 | 387 | 388 | 389 | 390 | 391 | 392 | 393 | 394 | 395 | 396 | 397 | 398 | 399 | 400 | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 | 409 | 410 | 411 | 412 | 413 | 414 | 415 | 416 | 417 | 418 | 419 | 420 | 421 | 422 | 423 | 424 | 425 | 426 | 427 | 428 | 429 | 430 | 431 | 432 | 433 | 434 | 435 | 436 | 437 | 438 | 439 | 440 | 441 | 442 | 443 | 444 | 445 | 446 | 447 | 448 | 449 | 450 | 451 | 452 | 453 | 454 | 455 | 456 | 457 | 458 | 459 | 460 | 461 | 462 | 463 | 464 | 465 | 466 | 467 | 468 | 469 | 470 | 471 | 472 | 473 | 474 | 475 | 476 | 477 | 478 | 479 | 480 | 481 | 482 | 483 | 484 | 485 | 486 | 487 | 488 | 489 | 490 | 491 | 492 | 493 | 494 | 495 | 496 | 497 | 498 | 499 | 500 | 501 | 502 | 503 | 504 | 505 | 506 | 507 | 508 | 509 | 510 | 511 | 512 | 513 | 514 | 515 | 516 | 517 | 518 | 519 | 520 | 521 | 522 | 523 | 524 | 525 | 526 | 527 | 528 | 529 | 530 | 531 | 532 | 533 | 534 | 535 | 536 | 537 | 538 | 539 | 540 | 541 | 542 | 543 | 544 | 545 | 546 | 547 | 548 | 549 | 550 | 551 | 552 | 553 | 554 | 555 | 556 | 557 | 558 | 559 | 560 | 561 | 562 | 563 | 564 | 565 | 566 | 567 | 568 | 569 | 570 | 571 | 572 | 573 | 574 | 575 | 576 | 577 | 578 | 579 | 580 | 581 | 582 | 583 | 584 | 585 | 586 | 587 | 588 | 589 | 590 | 591 | 592 | 593 | 594 | 595 | 596 | 597 | 598 | 599 | 600 | 601 | 602 | 603 | 604 | 605 | 606 | 607 | 608 | 609 | 610 | 611 | 612 | 613 | 614 | 615 | 616 | 617 | 618 | 619 | 620 | 621 | 622 | 623 | 624 | 625 | 626 | 627 | 628 | 629 | 630 | 631 | 632 | 633 | 634 | 635 | 636 | 637 | 638 | 639 | 640 | 641 | 642 | 643 | 644 | 645 | 646 | 647 | 648 | 649 | 650 | 651 | 652 | 653 | 654 | 655 | 656 | 657 | 658 | 659 | 660 | 661 | 662 | 663 | 664 | 665 | 666 | 667 | 668 | 669 | 670 | 671 | 672 | 673 | 674 | 675 | 676 | 677 | 678 | 679 | 680 | 681 | 682 | 683 | 684 | 685 | 686 | 687 | 688 | 689 | 690 | 691 | 692 | 693 | 694 | 695 | 696 | 697 | 698 | 699 | 700 | 701 | 702 | 703 | 704 | 705 | 706 | 707 | 708 | 709 | 710 | 711 | 712 | 713 | 714 | 715 | 716 | 717 | 718 | 719 | 720 | 721 | 722 | 723 | 724 | 725 | 726 | 727 | 728 | 729 | 730 | 731 | 732 | 733 | 734 | 735 | 736 | 737 | 738 | 739 | 740 | 741 | 742 | 743 | 744 | 745 | 746 | 747 | 748 | 749 | 750 | 751 | 752 | 753 | 754 | 755 | 756 | 757 | 758 | 759 | 760 | 761 | 762 | 763 | 764 | 765 | 766 | 767 | 768 | 769 | 770 | 771 | 772 | 773 | 774 | 775 | 776 | 777 | 778 | 779 | 780 | 781 | 782 | 783 | 784 | 785 | 786 | 787 | 788 | 789 | 790 | 791 | 792 | 793 | 794 | 795 | 796 | 797 | 798 | 799 | 800 | 801 | 802 | 803 | 804 | 805 | 806 | 807 | 808 | 809 | 810 | 811 | 812 | 813 | 814 | 815 | 816 | 817 | 818 | 819 | 820 | 821 | 822 | 823 | 824 | 825 | 826 | 827 | 828 | 829 | 830 | 831 | 832 | 833 | 834 | 835 | 836 | 837 | 838 | 839 | 840 | 841 | 842 | 843 | 844 | 845 | 846 | 847 | 848 | 849 | 850 | 851 | 852 | 853 | 854 | 855 | 856 | 857 | 858 | 859 | 860 | 861 | 862 | 863 | 864 | 865 | 866 | 867 | 868 | 869 | 870 | 871 | 872 | 873 | 874 | 875 | 876 | 877 | 878 | 879 | 880 | 881 | 882 | 883 | 884 | 885 | 886 | 887 | 888 | 889 | 890 | 891 | 892 | 893 | 894 | 895 | 896 | 897 | 898 | 899 | 900 | 901 | 902 | 903 | 904 | 905 | 906 | 907 | 908 | 909 | 910 | 911 | 912 | 913 | 914 | 915 | 916 | 917 | 918 | 919 | 920 | 921 | 922 | 923 | 924 | 925 | 926 | 927 | 928 | 929 | 930 | 931 | 932 | 933 | 934 | 935 | 936 | 937 | 938 | 939 | 940 | 941 | 942 | 943 | 944 | 945 | 946 | 947 | 948 | 949 | 950 | 951 | 952 | 953 | 954 | 955 | 956 | 957 | 958 | 959 | 960 | 961 | 962 | 963 | 964 | 965 | 966 | 967 | 968 | 969 | 970 | 971 | 972 | 973 | 974 | 975 | 976 | 977 | 978 | 979 | 980 | 981 | 982 | 983 | 984 | 985 | 986 | 987 | 988 | 989 | 990 | 991 | 992 | 993 | 994 | 995 | 996 | 997 | 998 | 999 | 1000 | 1001 | 1002 | 1003 | 1004 | 1005 | 1006 | 1007 | 1008 | 1009 | 1010 | 1011 | 1012 | 1013 | 1014 | 1015 | 1016 | 1017 | 1018 | 1019 | 1020 | 1021 | 1022 | 1023 | 1024 | 1025 | 1026 | 1027 | 1028 | 1029 | 1030 | 1031 | 1032 | 1033 | 1034 | 1035 | 1036 | 1037 | 1038 | 1039 | 1040 | 1041 | 1042 | 1043 | 1044 | 1045 | 1046 | 1047 | 1048 | 1049 | 1050 | 1051 | 1052 | 1053 | 1054 | 1055 | 1056 | 1057 | 1058 | 1059 | 1060 | 1061 | 1062 | 1063 | 1064 | 1065 | 1066 | 1067 | 1068 | 1069 | 1070 | 1071 | 1072 | 1073 | 1074 | 1075 | 1076 | 1077 | 1078 | 1079 | 1080 | 1081 | 1082 | 1083 | 1084 | 1085 | 1086 | 1087 | 1088 | 1089 | 1090 | 1091 | 1092 | 1093 | 1094 | 1095 | 1096 | 1097 | 1098 | 1099 | 1100 | 1101 | 1102 | 1103 | 1104 | 1105 | 1106 | 1107 | 1108 | 1109 | 1110 | 1111 | 1112 | 1113 | 1114 | 1115 | 1116 | 1117 | 1118 | 1119 | 1120 | 1121 | 1122 | 1123 | 1124 | 1125 | 1126 | 1127 | 1128 | 1129 | 1130 | 1131 | 1132 | 1133 | 1134 | 1135 | 1136 | 1137 | 1138 | 1139 | 1140 | 1141 | 1142 | 1143 | 1144 | 1145 | 1146 | 1147 | 1148 | 1149 | 1150 | 1151 | 1152 | 1153 | 1154 | 1155 | 1156 | 1157 | 1158 | 1159 | 1160 | 1161 | 1162 | 1163 | 1164 | 1165 | 1166 | 1167 | 1168 | 1169 | 1170 | 1171 | 1172 | 1173 | 1174 | 1175 | 1176 | 1177 | 1178 | 1179 | 1180 | 1181 | 1182 | 1183 | 1184 | 1185 | 1186 | 1187 | 1188 | 1189 | 1190 | 1191 | 1192 | 1193 | 1194 | 1195 | 1196 | 1197 | 1198 | 1199 | 1200 | 1201 | 1202 | 1203 | 1204 | 1205 | 1206 | 1207 | 1208 | 1209 | 1210 | 1211 | 1212 | 1213 | 1214 | 1215 | 1216 | 1217 | 1218 | 1219 | 1220 | 1221 | 1222 | 1223 | 1224 | 1225 | 1226 | 1227 | 1228 | 1229 | 1230 | 1231 | 1232 | 1233 | 1234 | 1235 | 1236 | 1237 | 1238 | 1239 | 1240 | 1241 | 1242 | 1243 | 1244 | 1245 | 1246 | 1247 | 1248 | 1249 | 1250 | 1251 | 1252 | 1253 | 1254 | 1255 | 1256 | 1257 | 1258 | 1259 | 1260 | 1261 | 1262 | 1263 | 1264 | 1265 | 1266 | 1267 | 1268 | 1269 | 1270 | 1271 | 1272 | 1273 | 1274 | 1275 | 1276 | 1277 | 1278 | 1279 | 1280 | 1281 | 1282 | 1283 | 1284 | 1285 | 1286 | 1287 | 1288 | 1289 | 1290 | 1291 | 1292 | 1293 | 1294 | 1295 | 1296 | 1297 | 1298 | 1299 | 1300 | 1301 | 1302 | 1303 | 1304 | 1305 | 1306 | 1307 | 1308 | 1309 | 1310 | 1311 | 1312 | 1313 | 1314 | 1315 | 1316 | 1317 | 1318 | 1319 | 1320 | 1321 | 1322 | 1323 | 1324 | 1325 | 1326 | 1327 | 1328 | 1329 | 1330 | 1331 | 1332 | 1333 | 1334 | 1335 | 1336 | 1337 | 1338 | 1339 | 1340 | 1341 | 1342 | 1343 | 1344 | 1345 | 1346 | 1347 | 1348 | 1349 | 1350 | 1351 | 1352 | 1353 | 1354 | 1355 | 1356 | 1357 | 1358 | 1359 | 1360 | 1361 | 1362 | 1363 | 1364 | 1365 | 1366 | 1367 | 1368 | 1369 | 1370 | 1371 | 1372 | 1373 | 1374 | 1375 | 1376 | 1377 | 1378 | 1379 | 1380 | 1381 | 1382 | 1383 | 1384 | 1385 | 1386 | 1387 | 1388 | 1389 | 1390 | 1391 | 1392 | 1393 | 1394 | 1395 | 1396 | 1397 | 1398 | 1399 | 1400 | 1401 | 1402 | 1403 | 1404 | 1405 | 1406 | 1407 | 1408 | 1409 | 1410 | 1411 | 1412 | 1413 | 1414 | 1415 | 1416 | 1417 | 1418 | 1419 | 1420 | 1421 | 1422 | 1423 | 1424 | 1425 | 1426 | 1427 | 1428 | 1429 | 1430 | 1431 | 1432 | 1433 | 1434 | 1435 | 1436 | 1437 | 1438 | 1439 | 1440 | 1441 | 1442 | 1443 | 1444 | 1445 | 1446 | 1447 | 1448 | 1449 | 1450 | 1451 | 1452 | 1453 | 1454 | 1455 | 1456 | 1457 | 1458 | 1459 | 1460 | 1461 | 1462 | 1463 | 1464 | 1465 | 1466 | 1467 | 1468 | 1469 | 1470 | 1471 | 1472 | 1473 | 1474 | 1475 | 1476 | 1477 | 1478 | 1479 | 1480 | 1481 | 1482 | 1483 | 1484 | 1485 | 1486 | 1487 | 1488 | 1489 | 1490 | 1491 | 1492 | 1493 | 1494 | 1495 | 14 |
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